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ANTI-INFLAMMATION: FINDING A NEW ROLE FOR HEAT SHOCK PROTEINS IN HUMAN HEALTH

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Heat shock proteins (Hsps) are highly conserved proteins and have been proven to protect prokaryotic and eukaryotic cells in most organisms against external stressors, whether environmental or pathophysiological. This defense mechanism probably depends on the roles of Hsps as molecular chaperones in governing proper protein assembly, folding and transport or as anti-apoptotic regulators of cell death pathways. Recent investigations on human inflammatory diseases indicate that Hsps may be involved in the process of inflammation. In this short review, we describe the general concept of heat shock proteins and inflammation and the new anti-inflammation role of heat shock proteins in various inflammatory diseases such as infection, autoimmune diseases, ischemia/reperfusion injury, cardiovascular diseases and chemical-induced diseases. The Hsps may act as autoantigens to stimulate the immune system and interact with inflammatory intracellular signaling pathways to regulate the inflammatory response. There are still unanswered questions about the heat shock response that require further investigation.

Les protéines de choc thermique (Hsps) sont des protéines hautement conservées qui protègent les cellules de la plupart des organismes procaryotes et eucaryotes contre les facteurs de stress externes, que ceux-ci soient d'origine environnementale ou pathophysiologique. Ce mécanisme de défense est probablement lié au rôle de molécule chaperonne des Hsps qui interviennent dans l'assemblage, le repliement et le transport des protéines ou qui agissent comme agents anti-apoptotiques (régulation de la mort cellulaire). Des recherches récentes sur les maladies inflammatoires humaines indiquent que les Hsps peuvent intervenir dans le processus d'inflammation. Dans le cadre de ce court résumé, nous décrivons le concept général de protéines de choc thermique et de l'inflammation ainsi que le nouveau rôle anti-inflammatoire des protéines de choc thermique dans diverses maladies inflammatoires telles que les infections, les maladies autoimmunes, les lésions d'ischémie/reperfusion, les maladies cardiovasculaires et les maladies d'origine chimique. Les Hsps peuvent agir à titre d'autoantigènes qui stimulent le système immunitaire et interviennent dans les voies de signalisation intracellulaire en cas d'inflammation pour réguler la réaction inflammatoire. Les questions qui restent toujours sans réponse à propos de la réaction au choc thermique doivent faire l'objet de recherches plus poussées.

HEAT SHOCK PROTEINS

More than forty years ago Ferruccio Ritossa (1962) made the first observation that elevated temperatures could trigger rapid and specific

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changes in chromosomal and metabolic activity in *Drosophila* salivary gland cells producing a "puffing" of chromosomes. Ritossa concluded that the new puffs were indicative of novel gene expression. Twelve years later, Tissieres et al. (1974) showed that, indeed, novel proteins were expressed in cells after brief elevation of temperature. These initial findings lead to the discovery of a large number of stress (heat shock) proteins in many prokaryotic and eukaryotic organisms, tissues, individual cells and subcellular structures. Although heat shock proteins (Hsps) may have different names according to species in which they have been discovered, their nucleotide and amino acid sequence are highly conserved. Based on their related functions and size, the Hsps are grouped into several families: the 110 kDa Hsps, the 90 kDa Hsps, the 70 kDa Hsps, the 60 kDa Hsps, small Hsps such as Hsp27 and ubiquitin (Currie & Plumier 1998). Hsp genes are regulated by heat shock transcription factors (HSFs). Under resting conditions, HSFs bind with Hsps in cytoplasm and are inactive. Under stressful conditions, Hsps are recruited to damaged or denatured proteins, leaving monomer HSFs free in the cytoplasm. HSF is activated through a multi-step process, involving its phosphorylation by protein kinases such as protein kinase C (PKC), its trimerization and its translocation to the nucleus where it binds to the heat shock element (HSE) in the promoter region of Hsp genes and initiates transcription. Hsp mRNA is transcribed and leaves the nucleus for the cytoplasm where new Hsps are synthesized.

All living organisms respond to a wide variety of stresses such as heat shock (HS), heavy metals, ischemia, sodium arsenite, microbial infections, nitric oxide, and antibiotics by synthesizing Hsps. Hsps are present in cytoplasm, mitochondria, endoplasmic reticulum and nuclei. Some Hsps are constitutively expressed at high levels (eg, Hsp90, Hsc70), whereas other Hsps are rapidly inducible to high levels in response to cellular stress (eg, Hsp70, Hsp27). Hsps primarily function as molecular chaperones and facilitate the refolding, assembling and stabilization of denatured proteins (Hartl 1996, Rogalla et al. 1999). Molecular chaperones have been defined as a class of proteins that mediate the correct folding of other proteins, but do not take part in the final assembly of the new structures (Ellis & van der Vies 1991). Hsp chaperoning activity occurs in both nonstressed and stressed conditions, and maintains cytoskeletal function and cellular homeostasis. In addition, several Hsps have anti-apoptotic roles, regulating the activity of caspases, c-Jun NH_2-terminal kinase (JNK), and the nuclear factor κB (NF-κB) pathway. Interestingly, the NF-κB pathway is regulated by inflammation and it is also regulating the inflammatory response (Beere 2001, Polla et al. 1998). This may provide the missing link between the heat shock proteins and inflammation. Here, we review the roles of Hsps in various inflammatory diseases and propose a new role for Hsps in regulating inflammation.

INFLAMMATION: PHYSIOLOGICAL AND PATHOLOGICAL

Inflammation is defined as "a fundamental, stereotyped complex of cytologic and chemical reactions that occur in affected blood vessels and adjacent tissues in response to an injury or abnormal stimulation caused by a physical, chemical, or biologic agent" in Stedman's concise medical dictionary (Dirckx 2001). The inflammatory response is triggered whenever body tissues are injured, whether by infectious agents (bacteria, virus, parasites), physical agents (burns, trauma, radiation), chemical agents (toxins, heavy metals, reactive oxygen species (ROS)), immunological agents such as certain antigens causing allergy and autoimmunity, or any other phenomenon, and it is essentially a vascular reaction. The main purpose of inflammation is the quick death and clearance of foreign pathogen or antigen as well as injury repair. The immune system is responsible for regulating inflammation by producing substances such as histamines, prostaglandins, cytokines, chemokines, and adhesion molecules. Cell types such as neutrophils, eosinophils, basophils, lymphocytes, macrophages, and mast cells and platelets are involved in the inflammatory process, releasing specific inflammatory mediators and initiating the intricate chemical cascade. In the early phase of inflammation, pro-inflammatory mediators cause a marked increase in vascular permeability, local blood flow, and cellular infiltration into the injured site. This early process is hallmarked by five cardinal signs: redness, swelling, heat, pain and loss of function. In the late phase of inflammation, mediators contribute to angiogenesis, tissue remodeling and regeneration, connective tissue formation, wound healing, phagocytosis, and apoptosis. While we often attempt to regulate or suppress inflammation, it is an essential physiological process, which begins following a sub-lethal injury and ends with complete healing (Florey 1970).

Under normal conditions, the inflammatory process is turned off as soon as possible to avoid its deleterious effects. Mechanisms involve activation of regulatory T cells and secretion of anti-inflammatory cytokines in the late phase of inflammation, helping the organism to suppress the process. CD4+ T cell can be divided into at least two different subsets that counterbalance each other (Mosmann & Sad 1996). T-helper type 1 (Th1) lymphocytes are the most prevalent type of CD4+ T cells, and they promote inflammation by activation of macrophages and production of pro-inflammatory cytokines such as interleukin (IL)-2, IL-6, IL-8, tumour necrosis factor (TNF)-α, and interferon (IFN)-γ. Counteracting the Th1 cells, the Th2 cells suppress inflammation and dampen macrophage activity by producing anti-inflammatory cytokines, IL-5, IL-10, and IL-13. To maintain body homeostasis, the immune system has to diagnose the need for inflammation, control the exact mix of inflammatory molecules, and regulate the process spatially, often at multiple sites, temporally and in

magnitude depending on the injury. If the inflammatory process is inappropriately regulated, spatially, temporally, or in magnitude of response, or fails to terminate, then the inflammation response itself can be pathological and become the cause of significant damage (Cohen & Efroni 2003). Severe infection such as sepsis and non-infectious systemic inflammation response syndrome (SIRS; eg, surgery, trauma, burns, cardiac arrest and resuscitation, acute allograft rejection, etc) can cause acute and over-activated inflammatory response. Sustained inappropriate inflammatory response causes chronic inflammation and plays a role in autoimmune diseases such as type 1 diabetes, rheumatoid arthritis and atherosclerosis (Wick et al. 2001). Pathological inflammation is a feature of many diseases and the regulation of the inflammatory response and the suppression of pathological inflammation is the focus of extensive research efforts.

HSPS PROTECT AGAINST INFLAMMATORY DISEASES

Infection diseases

Infection represents a stress for both the host and the pathogen. The host cell stress response is differentially regulated according to the type of infected cell and the type of pathogen, the microenvironment and the specific intercellular or intracellular communication (Polla et al. 1998). Pathogen toxins damage the host by triggering inappropriate inflammation, and the host is made sick by its own inflammatory reaction to pathogenic stimuli that trigger TNF-α, IFN-γ and other pro-inflammatory mediators (Calandra et al. 2002). Hsps are involved in cytoprotection against various pathogen infections. Hsp70 protects macrophages infected with *Salmonella choleraesuis* against TNF-α-induced cell death and induces immunoregulatory CD4+ T cells during the course of infection with *Listeria monocytogenes* (Yoshikai 1998). Hsp70 also protects rat pancreas from *Cerulein*-induced pancreatitis-like injury (Bhagat et al. 2000). Over-expression of Hsp70 inhibits bacterial lipopolysaccharide (LPS)-induced production of cytokines in human monocyte-derived macrophages, LPS-induced lung inflammation, septic shock and accelerates mouse recovery after endotoxic challenge (Ding et al. 2001, Vreugdenhil et al. 2003, Eaves-Pyles et al. 2000, Paidas et al. 2002). In addition, HSF-1 deficient (HSF-/-) mice produced greater amounts of pro-inflammatory cytokines and were more susceptible to endotoxin-mediated lethality compared with wild-type mice (Xiao et al. 1999). During viral infection, elevated Hsps inhibit specific events in the viral cycle leading to inhibition of viral replication (Santoro 1994), and in fact, Hsp70 may be the cellular mediator interfering with viral protein synthesis (Santoro 1997). Sodium arsenite, cadmium, azetidine, and HS, all induce the expression of Hsps and inhibit the synthesis of Sendai virus protein synthesis as long as Hsp synthesis is occurring in the

infected human cells (Santoro 1997).

Autoimmune diseases

Autoimmune diseases are the classic example of inappropriate inflammation. Recent experiments in the adjuvant-induced arthritis (AIA) rat model of rheumatoid arthritis (RA) have shown promising results using Hsp peptides to suppress the inflammatory injury. Nasal administration of Hsp60 180-188 peptides induces highly effective protection against AIA through generation of regulatory T cells that produce anti-inflammatory cytokines such as IL-4, TGF-β and mainly IL-10 (Prakken et al. 2002, 2003). Mycobacterial Hsp10 (Agnello et al. 2002) and Hsp70 (Wendling et al. 2000) have also been found to suppress AIA. A phase I clinical trial was performed treating early RA patients with dnaJp1 peptide derived from the *E. coli* Hsp (Puga Yung et al. 2003). Interestingly, oral treatment with dnaJp1 reduces the T cell proliferative response, IL-2, IFN-γ and TNF-α, and stimulates the T cells to produce IL-4 and replaces the majority of TNF-α-producing cells with IL-10 and IL-4 producing cells. Such treatment with dnaJp1 suggests that Hsps or peptides derived from Hsps will be suitable candidates for immune therapy in chronic arthritis. In addition, treatment with Hsp60 or its peptides can modulate the progression of autoimmune diabetes. Vaccination of non-obese diabetic (NOD) mice with peptides of Hsp60 successfully inhibits the development of spontaneous diabetes (Elias et al. 1997, Bockova et al. 1997). A double-blind, phase II clinical trial found that type 1 diabetes in humans is also susceptible to immunomodulation by p277 peptide of Hsp60 (Raz et al. 2001). The administration of p277 preserves the endogenous levels of C-peptide and is associated with lower requirements of exogenous insulin, revealing the suppression of β-cell destruction. Inflammatory bowel diseases (IBDs), such as ulcerative colitis and Crohn's disease, are characterized by chronic relapsing inflammation. Hsps induced by hyperthermia prevent leukotriene B4 production, subsequent neutrophil infiltration, epithelial damage, and alterations in tachykinergic control of smooth muscle in an experimental IBD (Goldhill et al. 1999).

Ischemia/reperfusion injury

Ischemia/reperfusion (I/R) injury is widely recognized as a significant source of morbidity and mortality in a number of clinical situations such as transplantation, trauma, liver, lung, or bowel resection and haemorrhagic shock. A hallmark of I/R is the production of reactive oxygen species (ROS) during the reperfusion phase and it is thought that the production of ROS mediates much of the post-ischemic tissue injury by causing direct cellular damage and/or acting as second messengers in the activation of cellular responses controlling cell death and inflammation. Inflammatory response such as lymphocyte activation, neutrophil infiltration, cytokine release and fibrosis exists in both the

acute and chronic phases of I/R injuries. Hsps are highly inducible by I/R injury through the activation of HSFs by ischemia (Tacchini et al. 1997). Heme oxygenases (HO)-1 or Hsp32 is upregulated with I/R and is thought to be not just anti-oxidative, but also a complex immunomodulator protecting against inflammation in I/R injury (Katori et al. 2002a, 2002b). Interestingly, the expression of Hsp40 and Hsp70 increases during lung rejection in human pulmonary allografts (Rizzo et al. 1998), and elevated levels of Hsp70 correlates with the improved pulmonary function after I/R in an isolated rabbit lung model (Long et al. 2003). The cytoprotective effects of Hsps have also been found in I/R injury in brain, liver, kidney and surgical flap (Plumier et al. 1997, Currie et al. 2000, Uchinami et al. 2002, Wagner et al. 2003, Rucker et al. 2001).

Cardiovascular diseases

Heat shock proteins are expressed in the cardiovascular system and appear to have a beneficial role. Currie et al. (1988) reported that whole body heat shock in rats is associated with improvement of cardiac functional recovery after global ischemia and these findings are correlated with significantly increased cardiac Hsp70. Transgenic mice expressing high level constitutive expression of the human inducible Hsp70 demonstrate the direct role of Hsp70 in the protection of the myocardium from ischemia and reperfusion injury (Plumier et al. 1995). In addition, heat shock treatment and the concommitant high levels of Hsp70 and Hsp27 and their phosphorylated isoforms protect against angiotensin (Ang) II-induced hypertension and inflammation in heart and aorta (Chen et al. 2004a, 2004b). Heat shock proteins have a role in the treatment of atherosclerosis. Using mucosal administration of Hsp65 Maron et al. (2002) vaccinated low-density lipoprotein receptor deficient (LDL-/-) mice to reduce the inflammatory process, hence provided a new immunologic approach for the treatment of atherosclerosis.

Other inflammatory diseases

There is also evidence for Hsps having a role in various other models of inflammation. Hsp25, Hsp32, Hsp47, and Hsp70 have been demonstrated to play an anti-inflammation role in some chemical-induced diseases such as acetic acid-induced gastric ulcer (Guo et al. 2002), thioacetamide-induced liver disease (Zborek et al. 2002) and carrageenin-induced pleurisy (Ianaro et al. 2001). Upregulation of Hsp70 also reduces inflammation in asthma and the acute respiratory distress syndrome (Bertorelli et al. 1998, Weiss et al. 2002). Thus Hsps are associated with inflammation.

MECHANISMS OF ANTI-INFLAMMATION REGULATION OF HSPS

Extra-cellular mechanisms: autoantigen role of Hsps

Hsps are now known to be strongly immunogenic despite their high level of evolutionary conservation (van Eden et al. 2003). While Hsps are intracellular proteins, they are also expressed on the cell surface (van Eden 2000). Most self-hsp cross-reactive T cells are also IL-10 producing regulatory T cells (van Eden et al. 2003). Three mechanisms of anti-inflammatory T cell induction by Hsps have been proposed (Van Eden et al. 2003): (1) *Mucosal tolerance*: Hsp reactive T cells recognize microbial Hsp epitopes in the gut lymphoid tissue and develop a tolerance when confronted with self-Hsps expressed elsewhere in the body. (2) *Altered peptide ligands regulation*: Microbial-Hsp reactive T cells perceive self-Hsp homologs as partial agonists or altered peptide ligands and redirect pro-inflammatory (Th1) T cell response to regulatory Th2 response. (3) *Anergy*: The ubiquitous low level of Hsp is also expressed on non-professional antigen presenting cells that lack the co-stimulatory molecules needed to induce a T cell response. This constitutive Hsp expression in non-professional antigen presenting cells in the absence of proper co-stimulation drives self-Hsp recognizing T cells into a state of anergy. Such "anergic" T cells inhibit the proliferation and activation of other T cells when confronted with professional or activated antigen presenting cells.

Intra-cellular mechanisms: crosstalk between Hsps and cell signaling transduction pathways

Recently, several studies show that Hsps interact with some intra-cellular signaling transduction pathways involved in inflammation. NF-κB is a pivotal transcription factor that functions to control the transcription of a variety of pro-inflammatory genes, including cytokines, growth factors, adhesion molecules, immunoreceptors and acute-phase proteins. The HS response and NF-κB signaling pathway are two fundamental cellular processes. The interaction between Hsps and HS response, and NF-κB pathway effect various levels of the pathway (Figure 1). Our laboratory (Chen et al. 2004a, 2004b) and others (Wong et al. 1997, Pritts et al. 2000, Yoo et al. 2000) have found that heat shock suppresses NF-κB activation by inhibiting the phosphorylation and degradation of its inhibitor, IκB-α. In fact Hsp70 through its molecular chaperone activity interacts and forms complexes with IκB-α and is thought to stabilize IκB-α and attenuate NF-κB activation (Shimizu et al. 2002). Hsp70 may also directly interact or chaperone NF-κB, as a partial substitute for IκB (Guzhova et al. 1997). Alternatively, the human IκB-α gene promoter region contains a contiguous 20 bp segment that matches with the heat shock element in the promoter region of Hsp genes (Wong et al. 1997). After heat shock (HS), both IκB-α and another

NF-κB inhibitor IκB-β are expressed and, thus, can be regarded as heat shock proteins (Wong et al. 1997, 1999, Stasiolek et al. 2000). HS inhibits radiation-induced activation of IκB kinase (IKK) (Curry et al. 1999, Yoo et al. 2000) and appears to increase intracellular phosphatase activity (Malhotra & Wong 2002). Consistent with this, HS decreases the cytoplasmic level of IKK-α (Chen et al. 2004b) and is correlated with the higher expression of Hsp70, Hsp27 and their phosphorylated isoforms. Interestingly, Park et al. (2003) found that Hsp27 interacts directly with IKK-α and IKK-β in down-regulation of TNF-α induced NF-κB activation via its phosphorylation. Hsp70/HS have also been found to suppress other proinflammatory pathways such as JNK and p38 (He et al. 2000, Wang et al. 2002) and it is likely that HS and Hsps will suppress pro-inflammatory and increase anti-inflammatory transcription factors.

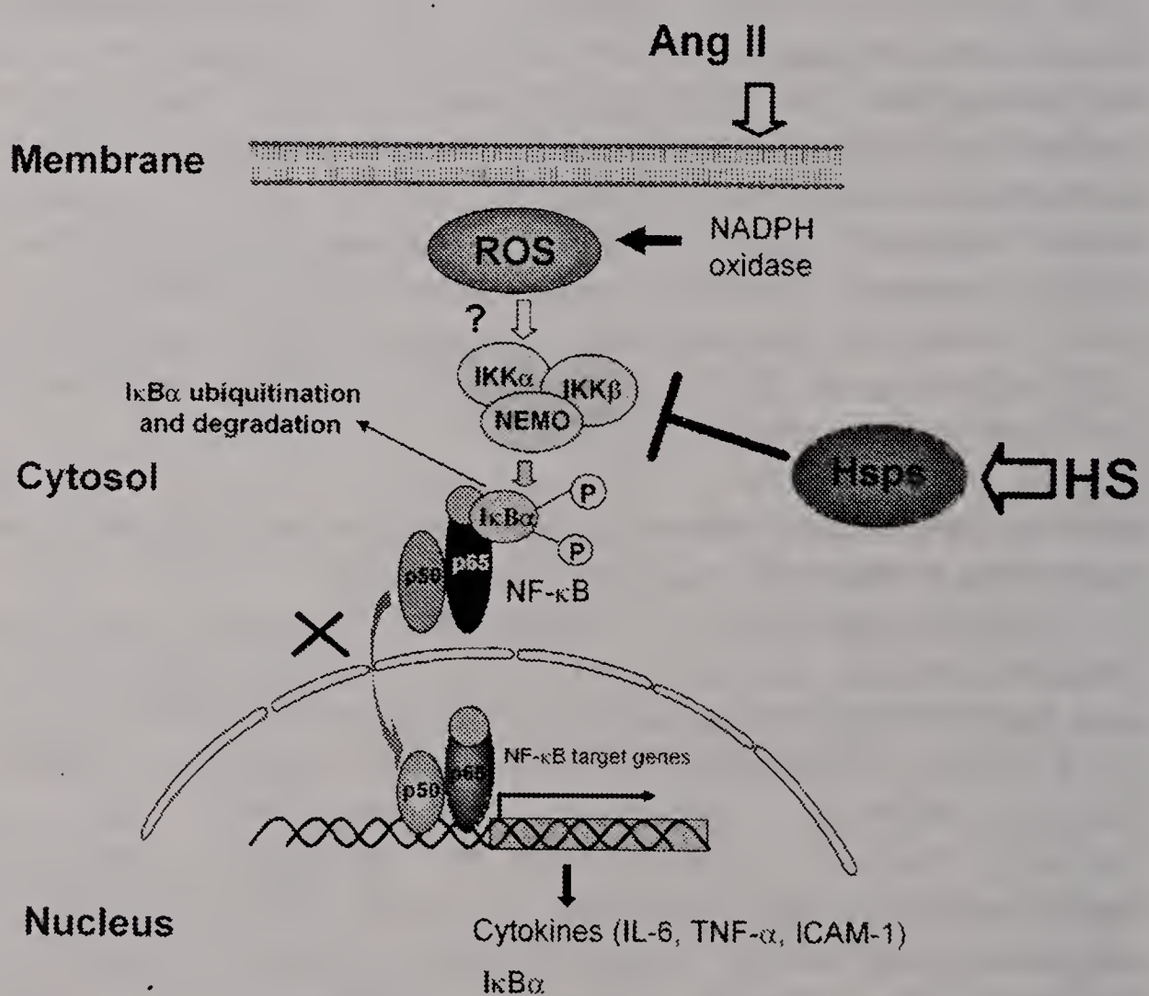

Figure 1. NF-κB pro-inflammatory signaling pathway. NF-κB consisting of p50/p65 subunits is normally resident in the cytosol and is maintained in an inactive form by its inhibitor IκBα. Angiotensin II (Ang II) stimulates NADPH oxidase to release reactive oxygen species (ROS) that are thought to activate the IκB kinase (IKKα, IKKβ, and their regulator NEMO) complex. The activated IKK complex phosphorylates IκBα and initiates its ubiquitination and degradation, exposing the nuclear localization signal on NF-κB. Freed NF-κB is translocated to the nucleus and binds to the promoter region of genes expressing pro-inflammatory cytokines such as Interleukin-6 (IL-6), tumor necrosis factor-α (TNF-α), intercellular adhesion molecule-1 (ICAM-1) and IκBα. Heat shock (HS) strongly elevates the expression of several heat shock proteins that interact with the IKK complex to suppress its activation.

PARADOXES OF HSPS AND PERSPECTIVES

As an alternative to controlling inflammation by using anti-cytokine treatments that are currently less than fully effective at controlling the many cytokines, regulation of Hsps may be a novel and more effective approach to anti-inflammatory therapy. In fact, many of the current widely used nonsteroid anti-inflammatory drugs (NSAIDs) induce HSF activation and increase the expression of Hsps (Polla et al. 1998). Paradoxically, not all aspects of the heat shock response are protective. Firstly, some Hsps, and especially the Hsp60 family have been found to induce macrophages to secrete pro-inflammatory mediators such as TNF-α, IL-6, IL-12, and nitric oxide (Ohashi et al. 2000, Flohe et al. 2003). Contradictory pro-inflammatory and anti-inflammatory effects of Hsp60 in various cell types may be because Hsp60 works as a ligand both for toll-like receptor-4 (TLR-4) and TLR-2 in T cells and B cells. Hsp60 and its fragments can regulate the physiology of inflammation itself by acting as ligands for TLR-2 (Zanin-Zhorov et al. 2003), while Hsp60 might elicit a potent pro-inflammatory response through TLR-4 signaling (Ohashi et al. 2000). Whether Hsp60 is a "smart" molecular switch in the regulation of inflammation requires further investigation. Secondly, HS and expression of Hsps can have contradictory effects such as being benefical *before* a pro-inflammatory stimulus (e.g., NF-κB activation), compared to cytotoxic effects *after* a pro-inflammatory stimulus (DeMeester et al. 2001). Such paradoxical effects in HS and NF-κB regulation may be involved in critical illnesses such as multiple organ dysfunction. Thirdly, sustained inflammation in some chronic diseases may be caused by the undesired prolonged survival of pro-inflammatory cells. The cytoprotective effects of Hsps during apoptosis, although beneficial in other pathologic conditions, may contribute to chronic inflammation. The increase in HSF activity and subsequent Hsp production may differentially influence three mitogen-activated protein kinase (MAPK) pathways under various stressful conditions (Malago et al. 2002). Hsps protect against apoptosis via ERK1/2 MAPK pathway, while they suppress inflammation through JNK and p38 MAPK activity. However, all three MAPK pathways can be activated at one time. A better understanding of interactions between Hsps and regulators of apoptosis and inflammation and how these interactions can be modulated by the levels of the Hsps needs to be investigated as an alternative approach for controlling inflammatory diseases.

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OCCURRENCE OF THE SWAMP LYMNAEA, *Lymnaea stagnalis* (GASTROPODA: PULMONATA) IN ATLANTIC CANADA

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The occurrence of the swamp lymnaea, *Lymnaea stagnalis* (Linnaeus 1758), a large, distinctive, pulmonate snail, has been documented in Atlantic Canada for the first time. It is unclear if the populations reported here are relictual, or whether *L. stagnalis* has been introduced into Atlantic Canada.

On a signalé pour la première fois, dans le Canada atlantique, la présence de la grande lymnée des étangs, *Lymnaea stagnalis* (Linné, 1758), un gros escargot pulmoné caractéristique. On ne sait pas si les populations signalées sont relictuelles ou si *L. stagnalis* a été introduit au Canada atlantique.

INTRODUCTION

Lymnaea stagnalis

In North America the swamp lymnaea, *Lymnaea stagnalis* (Linnaeus 1758), a pulmonate snail, occurs south of the tree line from the St. Lawrence watershed to the Mackenzie and Yukon watersheds, and south to Colorado and the Mississippi system in North Dakota, Ohio, and Illinois (Jokinen 1992). Although *L. stagnalis* has a wide circumpolar distribution, Athearn (1961), LaRocque (1961) and Davis (1990), do not list the species for New Brunswick or Nova Scotia. Clarke (1981) confirms that this mollusc is absent from Atlantic Canada. With the exception of an undocumented historical record from Maine (Tryon 1865), the swamp lymnaea is not known to occur in New England north of New York (Jokinen 1992). Nylander (1943) reported that *L. stagnalis* was abundant in post-Pleistocene marl deposits at Houlton, Maine and Bonaventure East, on the north side of the Bay of Chaleur, Quebec and commented that the species was conspicuous by its absence from northern New England.

There is, however, an unpublished historic record for *L. stagnalis* in New Brunswick that came to light recently during development of the

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New Brunswick Museum (NBM) mollusc collections database. Three *L. stagnalis* shells, which appear to have been collected as drift, bear the label "*Limnaea stagnalis*, lake near Campbellton, 1889, Harry Hall" (NBM 6737). Campbellton is located in northern New Brunswick at the head of the Bay of Chaleur. Two of the specimens are unbroken and are 34.5 mm and 38.1 mm in total length. The current status of any possible northern New Brunswick population is unknown since the precise location of collection remains uncertain.

Sampling area

Rockwood Park was established on 120 hectares in Saint John, New Brunswick in 1896; the Arches consist of four interconnected lakes and ponds created by damming a stream and by excavation between 1904 and 1906. The Park now consists of about 890 hectares of mostly undeveloped forestland within the Acadian Forest zone in the Southern Uplands physiographic region and is one of the largest in-city parks in North America. A series of low, discontinuous hills dominate the Park, with the region underlain primarily by limestones and dolomites. The Park receives about 250,000 visitors annually, including a significant number of campers from the eastern United States and elsewhere in eastern Canada (Watson 2003).

Here we document the presence of *L. stagnalis* in this park and comment on the status of the species' occurrence in the region.

COLLECTION AND IDENTIFICATION

On 23 July 2002 we collected nine specimens of *L. stagnalis* from two small mesotrophic ponds in Rockwood Park, The Second and Third Arches (45° 17.662 N 66° 03.517 W; NBM 4631). The nine specimens range in length from 33.8 mm - 41.6 mm (mean = 38.1 mm). Identification was confirmed by DFM using Clarke (1981) and reference material from Ontario, Manitoba and Michigan available in the NBM collection. New Brunswick specimens match the illustrations of *L. stagnalis jugularis* provided in Clarke (1981), but as McDonald (1969) notes the species is highly variable and the recognition of distinct geographic races in this species is questionable.

Further searches of the Arches in 2003 and 2004 specifically for *L. stagnalis* failed to reveal the species, as did investigations of the following nearby lakes within Rockwood Park in 2003: Lily Lake, Fisher Lakes, Cresent Lake, Harrigan Lake, Owen Lake, and Long Lake.

CONCLUSIONS

The apparent lack of persistence of *L. stagnalis* in Rockwood Park, coupled with its restriction to a man-made water body near a campground that hosts large numbers of visitors annually from within the documented range of the species, suggests that the nine individuals collected may have been introduced. Also, Matthew & Stead (1903) reported on preliminary investigations of freshwater molluscs collected in Saint John, including some from Rockwood Park, but they did not list *L. stagnalis*, a large and distinctive species.

McDonald (1969) reported that adult *L. stagnalis* "typically" range from 38-52 mm, while Boag & Pearlstone (1979) first observed oviposition at 30 mm. All New Brunswick shells reported here therefore appear to be those of mature or near mature animals. Although not precluding the introduction of juvenile or even adult *L. stagnalis* on exotic plants, the literature on age and size at sexual maturity suggests that the New Brunswick specimens reported here were at least in their second summer, and possibly their third (Berrie 1965, McDonald 1969, Boag & Pearlstone 1979). Further study will be required before it can be determined whether the occurrences documented here are relictual or whether *L. stagnalis* has been periodically introduced into Atlantic Canada, but with populations perhaps proving to be ephemeral.

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A RETROSPECTIVE: THREE QUARTERS OF A CENTURY AT THE HALIFAX FISHERIES RESEARCH LABORATORY

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In 1925 a Fisheries Technological Program was begun in temporary quarters on the Halifax waterfront to provide scientific research and technical assistance to improve the handling, processing and quality of fisheries products in Atlantic Canada. From that date through to 1979 (with a move to permanent buildings next door) studies on fish processing (smoking, drying, fresh and frozen storage, protein stability, marine oils, enzymatic and bacterial spoilage and grading systems among others) were conducted and the results transferred to industry, government and international agencies with a high degree of success and benefits. After it was apparent that product quality was affected by the condition of fish prior to harvest, more effort was devoted to physiological studies of live fish. In the 1960s studies concerning live lobster storage and latterly technical support for developing aquaculture ventures, i.e. health studies, nutritional requirements, environmental needs and physical structures, were added. Following the termination of the technological program in 1979 the buildings were used to accommodate elements of the Fisheries Resource Branch until they could be re-located in 1997. This retrospective traces the reasons for programs and offers brief sketches of the studies and their application.

En 1925, un programme d'études technologiques sur les pêches voyait le jour dans des locaux provisoires situés sur le front de mer d'Halifax (il a emménagé dans un édifice permanent tout près des locaux originaux par la suite). Le but du programme était d'assurer une aide scientifique et technique afin d'améliorer la manutention, la transformation, et la qualité des produits de la pêche au Canada Atlantique. De 1925 jusqu'en 1979, le programme n'a jamais cessé ses activités. On y a étudié la transformation du poisson (fumage, séchage, entreposage de produits frais ou congelés, stabilité des protéines, huiles marines, détérioration des produits provoquée par des enzymes ou des bactéries et systèmes de classement, entre autres choses), et on a transmis les résultats de ces études à l'industrie, aux gouvernements et aux agences internationales qui en ont retiré de nombreux avantages. Lorsqu'il est devenu évident que la qualité du produit est également influencée par l'état du poisson avant la récolte, on a

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commencé à consacrer davantage d'efforts aux études physiologiques du poisson vivant. Au cours des années 1960, on a ajouté des études sur les conditions d'entreposage du homard vivant et, plus récemment, on s'est intéressé aux besoins de l'industrie aquacole, à savoir l'état de santé des poissons d'élevage, leurs besoins nutritifs, leurs besoins liés au milieu et les structures physiques. Quand le programme d'études technologiques a pris fin en 1979, les édifices ont été utilisés par certaines composantes de la Direction des ressources halieutiques jusqu'à ce qu'elles aménagent dans d'autres locaux en 1997. Voici une rétrospective de la raison d'être des programmes, des études qui ont été menées et de leurs applications.

INTRODUCTION

In December 1978 the director of the Halifax Fisheries Laboratory, Dr EG Bligh, was instructed to notify his staff that the Fisheries Technology Branch was to be terminated across Canada at the end of the fiscal year, thereby ending a program begun in 1925. Although it was intended that work at all of the Technological Branch Centres would then cease and the centres be closed, it proved not to be possible immediately at Halifax. There was no other laboratory space available to accommodate the remaining continuing programs of the Fisheries Resource Branch i.e., the Disease and Nutrition Section and the Chemistry Section of the Fisheries and Environmental Sciences Division joined later by the Invertebrates and Marine Plants Division and elements of the Freshwater and Anadromous Division. By October 1997, however, these programs had been re-located and in January 1999 the buildings at 1707 Lower Water Street, Halifax, Nova Scotia by then known as the Halifax Fisheries Research Laboratory, were demolished after close to 70 years of expansions, modifications, renovations and rehabilitations.

Accordingly, this short sketch has been divided into two parts. The first covers the 53 years of the Fisheries Technology Program and the second part, the additional years of the Fisheries Resource Branch Program. Ultimately, following amalgamation of the Fisheries Research Program with the Ocean Science and Surveys Branch (OSS), the combined forces became the current Science Branch of the Department of Fisheries and Oceans (DFO).

THE FISHERIES TECHNOLOGY PROGRAM

What was the Fisheries Technology Program, what were its objectives and how did it come about? What in particular was its history at the Halifax site? To answer these questions adequately in relation to the Halifax Laboratory it is necessary to delve briefly into the history of the North Atlantic fisheries.

Historical Background

The Vikings were among the more daring and wide-ranging of the Atlantic explorers. For their day they ventured incredible distances on voyages lasting lengthy periods. As always on such voyages the supply of food and its preservation was a limiting factor. The Vikings solved this paramount problem through development of fish drying, primarily of cod.

These Viking explorations were followed several centuries later (toward the end of the fifteenth century) by other Europeans whose interests lay in finding a shortcut to the far east and the opportunity to make fortunes from the spice trade (Columbus and Cabot) as well as by the Basques, who may have preceded them, but whose interests lay in the rich fishing grounds. The Basques, in particular, had improved upon the Viking dried cod staple by salting as well as drying the fish. Their markets for fish had been fostered, in particular, by the 'fast (or lean) days' imposed by the medieval Catholic Church, during which meat was prohibited. As the fast days included every Friday, the 40 days of Lent, plus other days on the religious calendar, almost half the days of the year were 'lean days' which eventually became 'salt cod days' thus creating a huge Europe-wide demand for preserved fish. When word reached Britain and Europe generally, via the Cabot expedition, of the tremendous supplies of fish available, the European long distance fishery was initiated and became the basis of many fortunes in Britain, France, Spain and Portugal (Kurlansky 1997).

Thus, when the Atlantic explorations that were intended, initially, to exploit the spice trade with the far East were blocked by the unexpected presence of the Americas, this led in the south to exploitation of the gold and silver of Central and South America while in the north it led to the development of extensive fisheries. The fisheries actually fuelled the initial development and European settlement of North America to a far greater extent than did the fur trade; the importance of the fur trade came later. For example, the burgeoning New England society, based on fishing, led sequentially to agricultural and industrial development further inland. One of the more important fishery products of the 18th and 19th centuries was salted, dried cod. This stable preserved product became a staple and a major trade item sold widely in the Americas and, shamefully was used as part of the currency in the slave trade, in parts of Africa (Johnstone 1977, Kurlansky 1997).

As might be expected the presence of such rich fishing grounds led inevitably to many conflicts, skirmishes and outright wars. The point of importance to our story is that the extensive fishing by all of these national groups using hand methods (largely hook and line) and sailing vessels was, until the middle of the nineteenth century, essentially passive and relatively benign with regard to the impact on fish stocks.

With the advent of steam-powered vessels, however, fishing changed rapidly from a passive to a highly active form through the development and application of trawling techniques. The result, in the latter part of the nineteenth century, was an immense surge in the catches and what came to be recognized as over-fishing; an apparently startling new concept. In fact,

in 1883, despite evidence to the contrary, the highly influential scientist, Thomas Huxley had declared in the opening address at the International Fisheries Exhibition in London that there was no likelihood of fish scarcity through over-fishing, and that with existing methods of fishing, it was inconceivable that the great sea fisheries, such as those for cod, herring and mackerel, could ever be exhausted (Hubbard 1993). Although over-fishing came to be considered a real problem for fisheries on both sides of the Atlantic, over-fishing did not actually occur in the western Atlantic for some decades. Among the first to write with real insight on the over-fishing problem was Michael Graham (1943).

In the latter part of the 19th century no really clear picture of fish populations, stocks or their dynamics existed. Faced with the decline in catches, those involved in the fisheries cast about for the fundamental causes and arrived at two quite different possible explanations: 1) an actual decline in fish numbers, or 2) changes in availability imposed by alterations in fish migration and aggregation patterns possibly driven by changing oceanographic patterns. As a result two main courses were followed more or less in parallel.

The first was to assume, that as a result of over-fishing, a fish vacuum had been created. It was believed that the area still had all of the ingredients to support the vanished, but desired target species; all that was necessary was to replace the vanished stocks with larvae and young fish that could utilize the presumed huge surpluses of food. To rehabilitate these stocks a number of massive hatcheries were built by the United States at Woods Hole, Boothbay Harbor and Gloucester, by Britain at Dildo, Newfoundland and Dunbar, Aberdeen, Fleetwood and Port Erin in the home islands and by the Norwegians at Flodevigen and Trondheimsfiord (Shelbourne 1964). The program resulted in the release of billions of Gadidae and Pleuronectidae larvae and young fish annually. By World War II or shortly thereafter, lack of evidence of positive results and the high costs led to termination of these attempts to expand marine food fish resources. Some of these hatcheries became the foundation for some of the marine research laboratories of today.

The other part of these more or less parallel thrusts stemmed from the conviction that the problem was not wholly a scarcity of fish, but quite possibly and in part a result of changed migration patterns. As these migration and aggregation patterns were likely to be controlled by oceanographic elements altering environmental conditions, the argument developed early that a major emphasis should be placed on oceanography or as it was then called, hydrography. A coalescence of approaches eventually arose from the debates of the late 19th century concerning the state of commercial fisheries. This amalgam was to include attempts to understand the dynamics of fish production in relation to oceanographic features.

As scientists concerned with marine affairs, including fisheries, were few and far between and the oceans are so large and complex, it was obvious that international cooperation was essential. These debates and the need

for international cooperation to make effective use of limited resources led rather directly to the foundation in 1902 of the major fisheries umbrella organization the International Council for the Exploration of the Sea (ICES) (Stewart 1991, Rozwadowski 2002) and underscored the need for a scientific underpinning for fisheries. This in turn led to the expansion of studies in those few countries which had work in hand and to the foundation of formal structures in those countries where the effort was minimal or non-existent, such as Canada (Johnstone 1977). At the time marine biology everywhere consisted largely of taxonomy and descriptive work. Much more was required by all of the fishing nations of the north Atlantic, however, if the devastating economic blow of the decline and failure of the fisheries was to be assuaged. Although there was general recognition that fisheries were in trouble, the fundamental principles governing the production and interactions of fish populations were not understood. It was also recognized that the necessary science to acquire these principles and develop sound management practices, by and large, did not exist. Individual national efforts were either being reinforced or created; although many of these efforts were small, it was not possible then to do much better quickly. Money was scarce, but so were trained people, facilities, equipment, methodology and most importantly the clear objectives upon which to focus activities.

The formal recognition by Canada for the need for science in dealing with the problems of fisheries resulted in the appointment, in 1893, of Dr EE Prince as federal Commissioner of Fisheries. A specialist in fish embryology, he came to the post from the position of Professor of Zoology and Comparative Anatomy at the University of Glasgow. One of his first moves was to advocate a marine scientific station for Canada. In 1898, a memorial, addressed to the Government of Canada, advocating a floating station was approved, money was appropriated and a Board of Management of the Marine Biological Station of Canada was formed (incorporated in 1912 as the Biological Board of Canada). The floating laboratory, completed in June 1899, was located first at St. Andrews and work was begun that summer by three scientists from the University of Toronto, RR and BA Bensley and Joseph Stafford plus the director, EE Prince; with it fairly solid summer programs were conducted through to 1907.

In 1907, the floating station was moved to the north shore of the Gulf of St Lawrence at Seven Islands, then the location of a whaling station. Unfortunately, the scow upon which the laboratory was being carried developed a leak and was beached at Grande Vallée, Québec for repairs. Although the laboratory was then put on shore and repaired, it was eventually abandoned. As the value of a marine laboratory had been proved the Board of Management decided to build a permanent station at St Andrews, New Brunswick. This laboratory was opened in the early summer of 1908 shortly before its newly built west coast sister station at Departure Bay, near Nanaimo, BC.

While studies at these two stations proceeded, work elsewhere had

been making rapid strides in obtaining knowledge of the oceans and fish resources of northern Europe. Methods of aging fish using scales and otoliths were discovered. In Norway, Johan Hjort had published an important paper 'Fluctuations in the great fisheries of northern Europe' (Hjort 1914). This 228 page paper was one of the most important contributions to fisheries as it united all strands of fisheries science. The central thesis was that fluctuations of fisheries were not caused by over-fishing, migrations or currents, but by the varying success of year classes. A crucial question remaining was what caused good or poor year classes; Hjort regarded the early stages of fish life as critical and believed that fluctuations were closely related to availability of plankton. Thus, Hjort's hypothesis brought together two major lines of endeavour, i.e., fisheries investigations of populations and attempts to quantify the productivity (plankton) of the seas.

The question arose as to whether similar happenings also occurred in the western Atlantic and, if so, were these events synchronized with those in Europe? In 1914, it was decided to invite Dr Hjort to come to Canada to study samples of herring collected from northeastern Newfoundland to Massachusetts. An indication of the success of this visit was an invitation to Dr Hjort to lead a major survey in Canadian waters in 1915, the Canadian Fisheries Expedition. It included Norwegian, Canadian and United States workers and was to determine whether several different races of herring existed, to look for different rates of growth in different waters, to obtain information on year class strengths and past fluctuations in abundance, and to study the regime of ocean temperatures, salinities, currents and plankton contents in east coast waters.

This extensive and intensive venture, the Canadian Fisheries Expedition, was extremely successful and can be regarded as a landmark because of its influence on fisheries and marine sciences in Canada. Not only did it provide an immense amount of information, but it introduced methods of investigation developed in Europe which changed the Canadian style and direction of marine research i.e. combined operations which included physical oceanography, qualitative and quantitative plankton studies, studies of the eggs and larvae of commercial species of fish and detailed herring biology. Unfortunately, the Canadian Fisheries Expedition of 1915 led by Hjort could not be continued in 1916 because of World War I.

Much of Hjort's influence stemmed from the fact that the Expedition greatly impressed a young Canadian participant, AG Huntsman, recently named Permanent Curator of the Biological Station at St Andrews. He was shortly to become Director of the Station and one of the most influential figures over the next 20 years in the Biological Board's research policies. In addition to the object lessons Hjort offered in the area of field studies, Huntsman was also heavily influenced by Hjort's proposals and demonstrations for improving the quality of fishery products so that they would command higher prices in the market place. This in turn provoked interest in fish processing, an element that was to be influential in the eventual establishment of a technological program. At this point the story diverges into several separate branches. Anyone who wishes to have more

information on the highly important Canadian Fisheries Expedition of 1915 and its ramifications for Canadian marine sciences should consult Johnstone (1977) and Hubbard (1993) among others. The voluminous (527 pages) report of the Canadian Fisheries Expedition (Hjort 1919), according to EE Prince, was rated at that time by "a leading American authority as the most valuable piece of marine and fisheries work accomplished in North America" (Hubbard 1993).

When Hjort returned to Canada in 1915 he actually came with two objectives. The first was to lead the Canadian Fisheries Expedition and the second was to introduce a patented method for quick-freezing fish. He had noted in the previous year the inferior quality of the Canadian 'fresh' and 'frozen' fish that resulted in low prices on the international and domestic markets and had commented, "That the excellent Atlantic salmon, the haddock and other fishes are salted" indicated "more than anything else the difficult position of the industry" (Hubbard 1993). Hjort had also observed that the practices in the herring fishery employing fixed gear caught coastal, mature, inferior herring rather than fat herring as caught offshore in Norway by using drift nets and purse seines.

As partial fulfillment of his second objective, Hjort wished to ensure that the Canadian Fisheries Expedition be conducted in the "closest possible touch with the industry and give practical results" (Hubbard 1993). To that end he recommended that fish freezing experiments be conducted in tandem with the Expedition. Accordingly, he carried out a demonstration of the Ottesen patent method for freezing fish which was stated to be "the only method of freezing which is cheap, rapid and perfectly preserves all the best food qualities of fish" (Hubbard, 1993). The demonstration consisted of freezing large fish in a barrel full of brine and ice at –13F (-25C) in twenty to forty minutes i.e. approximately one third the time required with the air-freezing methods then in common practice. The results impressed everyone: fishermen, merchants and scientists and especially AG Huntsman. Unfortunately, with Canada now at war the cost of adding widespread demonstrations of freezing techniques to the overall expedition appeared prohibitive and that part of Hjort's proposal was turned down.

The lesson learned from Hjort, however, was not forgotten i.e. much greater economic returns could be realized by paying attention to production methods that enhanced product quality. Fish handling experiments were initiated by the Biological Board in 1915 especially to standardize curing methods using perfectly fresh fish. Despite equivocal results, Huntsman had these experiments repeated in 1917 with some improvements noted. The need for this kind of study in World War I was underscored by the complaints coming from overseas from both Canadian and British troops that the Canadian fish rations prepared from frozen Canadian fish were uneatable, tough and tasteless.

Prior to opening of the Atlantic Fisheries Experimental Station in 1925 the Biological Board of Canada did not have the facilities or mandate to carry out intensive research into fish processing. Individual members, however, influenced by Hjort and recognizing the paramount needs, did put

increased effort into applied work to improve the fisheries and products. Without tracing out all the lines that eventually culminated in the technological programs it is clear that the various complaints about quality, the low prices and the recognition that matters did not have to remain this way, led to action in 1924. Unfortunately, as pointed out by Hubbard (1993), although the Department of Marine and Fisheries, convinced of the necessity, placed the Biological Board of Canada at the forefront of its actions to aid industry, the Department never had the funding to implement the extensive measures the fisheries needed. The result as noted by Stewart Bates in 1944, was that little in the way of modernization and industrialization had occurred in the Canadian Atlantic fishing industry to that date (Hubbard 1993).

In contrast with fisheries, American agricultural food industries, followed by those in Canada, extended careful grading to ensure freshness and quality, improved packaging, increased advertising to build consumer preferences and also generally improved methods of production, processing and marketing. In fisheries, the most notable change in the periods between World War I and World War II was the slow change away from salted fish to the fresh and frozen products (Hubbard 1993).

The Technological Program

In 1923, the Biological Board of Canada [re-named the Fisheries Research Board of Canada (FRBC) in 1937] was re-organized to accomplish a number of ventures including investigation of the technological problems of the fishing industry. A sum of $70,000 had been voted to finance the development of two new technological stations, one at Halifax, Nova Scotia and the other at Prince Rupert, BC (later moved to Vancouver); this would aid the Board in fulfilling its expanded responsibilities in education work in connection with fisheries. Ultimately these two stations would be joined by another station at Grande Rivière, Québec, and Technological Units at London, Ontario (later moved to Winnipeg, Manitoba) and St John's, Newfoundland.

The station to be located in Halifax at the King's Wharf, named the Atlantic Fisheries Experimental Station (AFES), was housed initially in some vacant federal buildings that were refitted during 1924 to accommodate the work (Fig 1). A subcommittee on education appointed by the Biological Board of Canada met in March 1924 to consider the educational work in fisheries and made the following recommendations:

> 1) That a Director be appointed at the earliest possible date to initiate and carry out educational work.
> 2) That the said Director procure information on the technology processes of fisheries as a preliminary step to conducting a scheme for educational work.

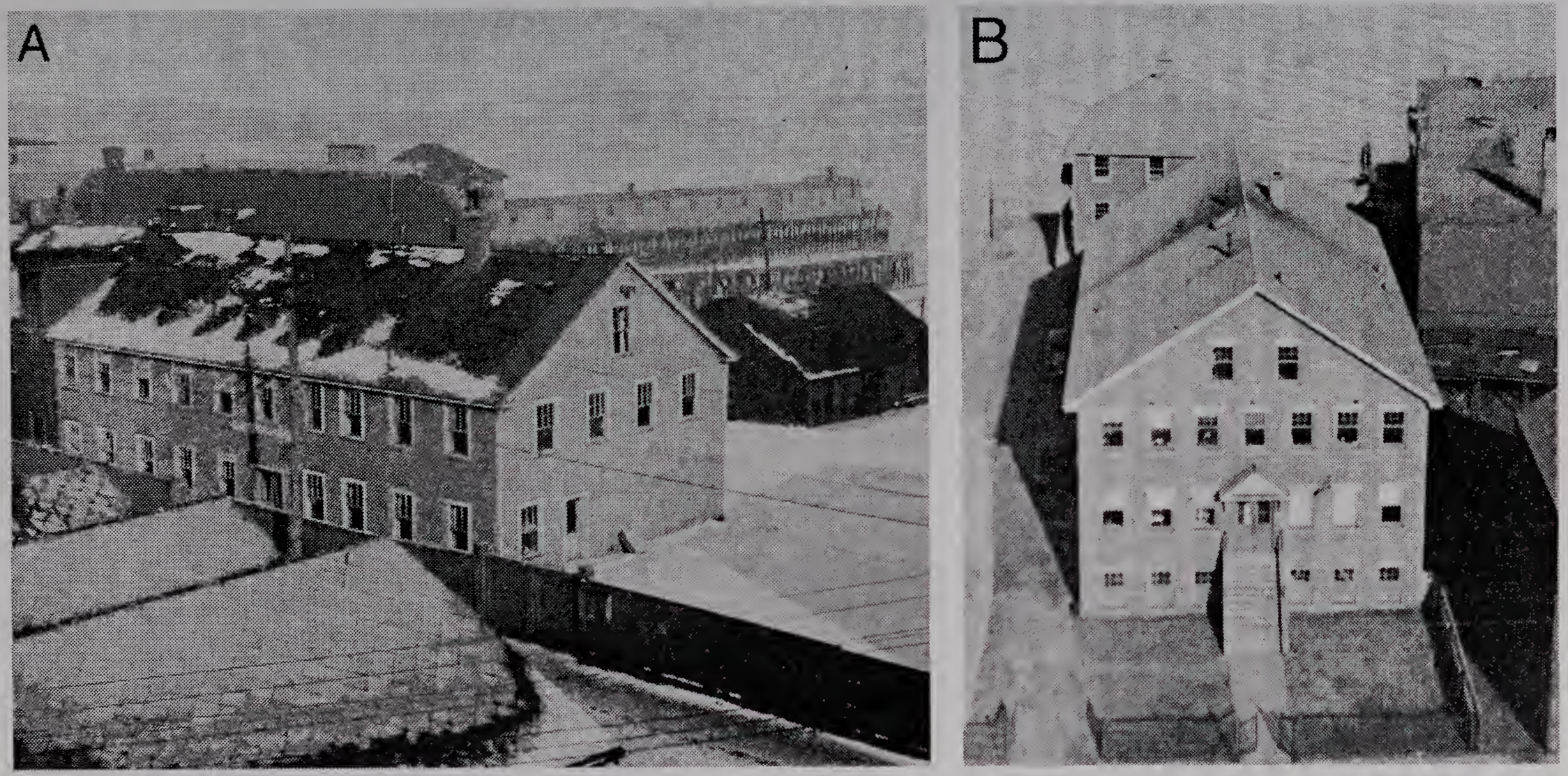

Fig 1. The temporary building occupied in 1925 by the Atlantic Fisheries Experimental Station, 1721 Lower Water Street, Halifax (labeled “A”) and the purpose built structure at 1707 Lower Water Street (labeled “B”) occupied in 1930.

3) That there be prepared as regularly as possible pamphlets for issue on matters of educational interest and in connection with the work of the Biological Board.
4) That the said Director plan the equipment of the Station so that it may be used for demonstrating fishery methods and processes" (Johnstone 1977).

After considering all applicants for the directorship it was decided to request AG Huntsman to take the post while also retaining the directorship of the St Andrews Biological Station as he was regarded as a 'glutton for work' and had been influenced greatly by Hjort and Knight (a senior Biological Board member) on the value of applied science (Johnstone 1977). He accepted this appointment and directed studies through to 1928, and in fact continued some studies on processing after his return to full-time duties at St. Andrews. The building at the King's Wharf was ready by the spring of 1925 [replaced by a purpose-built laboratory next door in 1930-31 (see Fig 1, 2)]. The first investigations undertaken dealt with the smoking of fish.

Fig 2. The much modified final form of the building at 1707 Lower Water Street in the 1970s (by then known as the Halifax Fisheries Research Board Laboratory). At its peak in the 1960s it provided facilities for around 90 staff.

Smoked Fish and Salt Fish Innovations

The smokehouses of the day were devoid of environmental controls and therefore it was not uncommon for the fish to either dry out or cook while being processed. Research showed that the best tasting "finnan haddies" were smoked after the fish had passed through the stage of rigor mortis, and that a light smoking produced the best results.

In 1937, AFES engineers developed a prototype mechanical smokehouse which became the standard for the Atlantic fish industry. In addition to ensuring quality control, it reduced smoking time from 15 hours to 7 hours. A further improvement in the design dropped that to three hours, enabling the production of 400 pounds of smoked cod fillets per hour.

As the foggy and humid weather conditions in Newfoundland were not conducive to salt fish drying, some of the salt fish shipped to the major Caribbean salt fish markets arrived mouldy. Scientists and engineers at the Halifax Laboratory applied yet another mechanical solution. The mechanical salt fish dryer they developed was the first in Canada, and is believed to have been among the first in the world. "It meant the salvation of the salt fish industry in the Maritimes," recalls Dr. Graham Bligh, the last Director of the Halifax Laboratory. As well, the AFES engineers made major improvements in applying refrigeration i.e. insulated fish holds, the incorporation of refrigeration in railway cars, and refrigerated live lobster holding units for retail outlets.

Frozen Fish

Perhaps the Halifax Laboratory's most striking claim to fame was the production of the world's first commercial-scale frozen fish in 1929. More than 16,000 pounds of "Ice Fillets" produced between April 1, 1929 and March 30, 1930 were shipped to Toronto for sale. They were called "Ice Fillets" because "frozen fish" connoted an inferior product in those days. The merits of the approach can be gauged by the fact that the Ice Fillets commanded a price 50 percent higher than "fresh fillets" of haddock kept on ice. In the words of one Toronto hotel manager, "The quality of this fish covering all kinds sent was perfect. The meat was firm, the juices were intact, in fact we in this country have never tasted such perfect fish as what you shipped to us" (Hubbard 1993).

In order to prevent fish from drying out while in cold storage, it became necessary to maintain humidity in the cold storage room. To this end, the first "jacketed cold storage room" was built at the AFES in 1927. This was accomplished by surrounding an experimental cold storage room with a jacket of circulating air which prevented the moisture of the fish from migrating to the refrigeration coils. This system proved to be particularly useful on the West coast where unpackaged fish was placed directly into freezer holds. Further enhancements to the jacketed cold storage system were made at the FRB Atlantic Biological Station in St. Andrews, New

Brunswick and at the FRB Fisheries Experimental Station in Prince Rupert, British Columbia.

The AFES also received world-wide recognition for its noteworthy contributions made over the years in the area of frozen fish including the importance of rapid freezing, low temperature storage, the detrimental effects of fluctuating storage temperatures, the biochemical and physical changes continuing in the proteins and fats in the fish during frozen storage and various tests for evaluating the quality of frozen products (e.g. protein solubility tests and measuring increases in free fatty acid values).

Fish Protein Concentrate and Minced Fish Products

During the 1960s the FRB Halifax Laboratory played a significant role in the development of Fish Protein Concentrate (FPC or fish flour), the technology that was to convert underutilized fish and edible fish wastes into a super protein to nourish the starving people of the world. Although a superior product was produced, FPC never gained commercial acceptance and the Halifax Laboratory went on to develop technology related to minced fish. Research showed that minced (or de-boned) fish tissue deteriorated more rapidly than intact muscle due to the release of enzymes and the incorporation of air. Nevertheless, minced fish technology advanced quickly here and elsewhere and now is utilized in producing a variety of value-added products including artificial crab legs (surimi) etc.

Fish Oils and Fatty Acids

Lipid extraction methodology

From the Halifax Laboratory's focus on reducing fish spoilage, several breakthroughs of international interest evolved in the area of fish oils and fatty acids. In order to monitor the biochemical processes that take place in frozen fish, it became necessary to extract the lipids at various intervals to determine at what point deterioration took place. Existing methods were not only laborious, but they were also destructive, and so in 1959 a method employing chloroform and methanol was devised which produced high-quality lipid extractions from wet fish tissue within minutes. The process, recognized as a "Citation Classic" is still employed worldwide in the analysis of lipids from a variety of plants and animals.

With regard to the original intent - to investigate the causes of lipid breakdown during the frozen storage of lean fish - the scientists identified the enzymes that were responsible for the release of fatty acids. Their recommendation to preserve the integrity of the lipids included maintaining a temperature low enough to slow the actions of the enzymes responsible for denaturation.

Fatty acid compositions: analysis

The advent of gas liquid chromatography in the mid-1950s precipitated a revolution in the field of fish oil analysis. An analysis that used to take three to four months could now be completed in an hour, and scientists were suddenly able to identify the fatty acids in fish oils rapidly and to trace changes in them. Scientists identified the particular fatty acid compositions of different fish oils, such as herring and capelin oils, enabling them to be used industrially in varnish and paints. Although in these products fish oils were displaced by polyvinyls in the 1960s, fish oils continued to be used in margarine and shortenings until they were replaced by 100 per cent vegetable oil.

From 1965 to 1970, the medical community began to preach the merits of fish as excellent sources of polyunsaturated fatty acids - just what the doctors were prescribing for the heart. At that time, the Halifax Laboratory provided companies such as Connors Brothers and National Sea Products with information about fatty acids which could then be supplied to nutritionists and dietitians.

In 1975, the Danish government dispatched two biochemists and a team of medical specialists to Greenland to study why the Inuit only rarely died of heart disease. They concluded that the Inuit ate seals, which have a fat with fatty acids similar to fish oils, and that certain long chain fatty acids unsaturated in the omega-3 position, were particularly healthful. Analyses by experts in fish oil compositions at the Halifax Laboratory provided the basis for some of these studies. When the technology branch was dissolved in the late 1970s, the fish oils section relocated to the Canadian Institute of Fisheries Technology at the Technical University of Nova Scotia, where the work related to this theory was completed.

During World War II, rapeseed, which contains a long chain fatty acid, had been used as a lubricant for steam engines. With the financial support of the Department of Agriculture, a new rapeseed cultivar was developed that produced both low erucic acid and glucosinolate levels. Between 1970 and 1975, studies at the Halifax Laboratory on the elimination of the undesirable erucic acid content in rapeseed oil contributed significantly to the development of the world's first canola oil, which now accounts for 95 percent of the edible oil used in Canada.

While some of the scientists working in the area of fish oils focused on defining fatty acid compositions, still others were advancing scientific knowledge in the area of oxidative rancidity in the storage of frozen fish. The high content of unsaturated lipids in fish promotes rapid oxidation, and it was discovered that fish oils exposed to metals oxidized even faster. Scientists at the AFES also found that blood products catalyze rancidity, and that washing the blood from fish tissues protected the product from the development of rancidity.

In addition, much of this work on the marine oils provided the basic information that led to subsequent commercial exploitation of the various components. A number of the commercial products now being produced locally arose largely as a result of this work.

Fish Spoilage and Grading

At the same time, as the marine oils work proceeded, chemists and bacteriologists focused on the other factors contributing to the rapid spoilage of fresh fish. The importance of good sanitation and the prevention of bacterial contamination were stressed. Procedures for the proper handling and icing of fresh fish and fillets were recommended to industry along with methods for salting, smoking and canning of fishery products. In all of these studies, the emphasis was on the fundamental aspects of fish as food. To this end the scientific studies focused on the proximate concentration in terms of fats, proteins, carbohydrates, nucleotides, nucleosides, purines, pyrimidines etc., followed by basic studies on their stability under varying temperatures and conditions. Not only were the changes in triglycerides/individual fatty acids and protein denaturation followed, but the agents of change (spoilage) i.e. fish enzymes, bacteria and chemical factors were identified and means were devised to prevent the changes. In addition, once the chemistry of the changes was revealed the various products of change could then be used as indices of quality to assign specific grades denoting fish quality, thus allowing grading to be based on highly objective analytical tests instead of the rather imprecise organoleptic testing then in use. The development of grading techniques and tests for quality (e.g. the trimethylamine test, hypoxanthine etc.) were important advances which together with other technological information, formed the foundation for fish inspection regulations. This information was used to develop fish inspection systems, which were then used to train staff and to found a Fisheries Inspection Service. This information was provided also to the industry through formal training programs, workshops and the distribution of printed "Circulars" and the Atlantic Progress Reports. Several long-term studies were aimed at inhibiting bacterial spoilage and included the use of antibiotics, gamma irradiation and super-chilling.

Until the 1960s studies at the Halifax FRB were concerned primarily with improvements in preventing deterioration of catches of fish and fisheries products from the point of harvest at sea through to delivery to the consumer. The goal was to determine and introduce procedures and practices that would achieve this through grading systems to measure and assign quality designations for the fresh or frozen products.

Gradually as studies devoted to product quality gained ground, it also became apparent that quality was not solely a function of post-mortem changes wrought by resident enzymes and bacteria associated with the fish (skins and viscera). The quality of the fisheries products was also influenced to a large degree by the stage of their life or annual cycles that the fish or shellfish were in prior to capture.

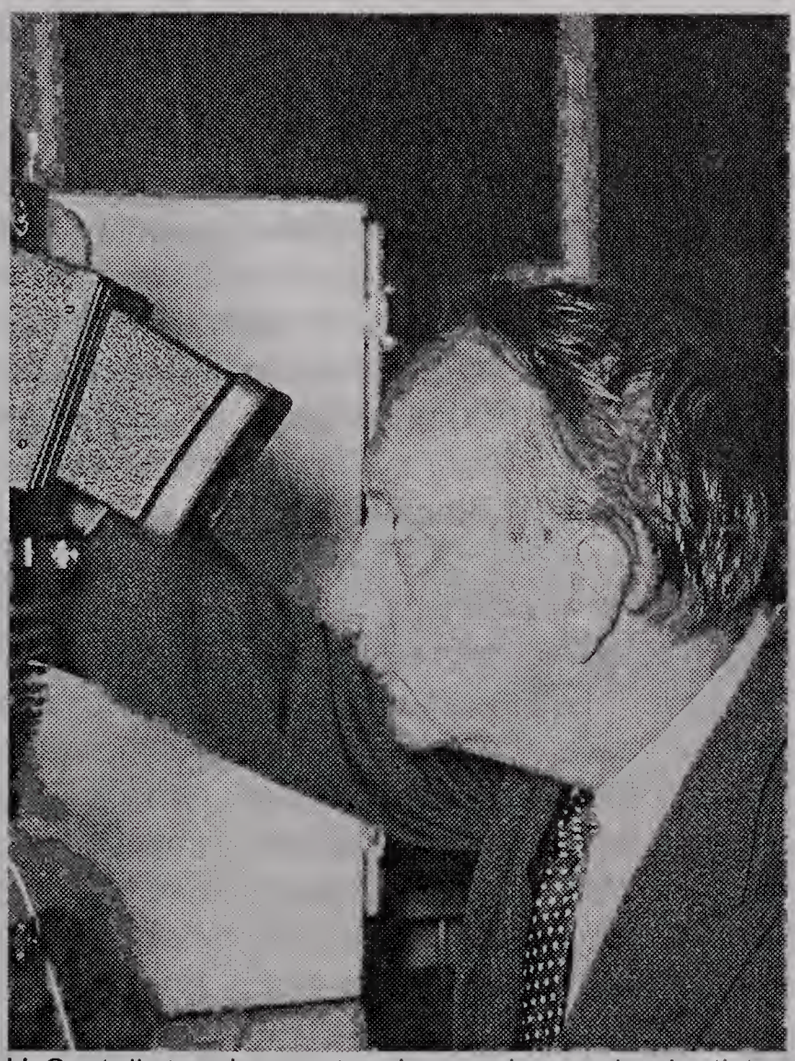

Fig 3. Charles H Castell, teacher, extension worker and scientist as described in one citation: "He has almost single handedly substantially improved the industrial practices concerned with fresh fish and in so doing added materially to the income of the Atlantic Fisheries industry ... His more outstanding achievements stemmed directly from his ability to communicate with all levels of people from top to bottom in the fishing industry and in government circles. He managed to put across a system of voluntary grading and later a Federal Fisheries Service grading and inspection system which was effective because he had worked hard to make it acceptable to both sides. The system itself was based upon Mr. Castell's research work which he managed to conduct while doing the field work on the fresh fish industrial practices ... "

Live Animals Added To The Laboratory Focus

Accordingly, more and more effort was directed to studying the condition of the live fish and shellfish and integrating this information into the studies which had preceded them to give a more comprehensive approach to ensuring quality products. In addition, problems of varying degrees of complexity arose in which live animals figured more prominently and required additional techniques and approaches. Many of these studies arose from the continuing needs of the harvesting/processing part of the fisheries while others originated with requests from the allied Biological Stations of the Fisheries Research Board. The interests of the new director, Dr David Idler, and enhanced resources added impetus to this enlarged perspective. From his work as a scientist at the Vancouver Station on the chemistry and biological function of hormones in the extended migrations of the Pacific salmon species, Dr Idler retained an interest in live animal studies. He was especially interested in applying these techniques and

findings to Atlantic salmon. At the beginning of his term in office a full-scale fresh and salt water working aquarium was built. Equipped with sources of good quality water, a system of large, intermediate and small tank units was supplied with seawater or freshwater maintained at various temperatures; these could be operated on either open or recirculating water systems.

From 1962 onward, a wide variety of studies on live animals (both fish and shellfish) were carried out. These included studies on the chemistry and physiological function of steroid hormones especially in Atlantic salmon and skates, detection of physiological forms of antifreeze in cold water species, digestive enzymes, isoenzymes/starch gel electrophoresis to discriminate between populations, histology, diseases, nutrition, contaminant absorption, and the influence of hydrocarbons on animals and thus on the quality of the derived fisheries products.

As the FRB became recognized as an authority on marine life in general, fishermen brought all manner of exotic sea life to the Lower Water Street facility over the years. One of the more memorable examples was "Timothy the Turtle". In 1971, a live leatherback turtle weighing about 1,000 pounds was donated to the AFES and put in the large deep tank at the rear of the building at 4:00 PM. The plan was to use him in the marine oils program the next day. At 7:00 the next morning, news of "Timothy the Turtle" was broadcast live by radio and several hundred people flocked to the Halifax Laboratory to catch a glimpse (Fig 4).

Fig 4. The crowd drawn in 1971 to the 1707 Lower Water Street rear tank building by the news of "Timothy the Turtle".

As the crowds and the objections by various groups prevented any work taking place it was decided, after much discussion, to release him at sea. In order to take him out of the tank, part of the building had to be removed; a mobile crane then lifted him from the tank and hoisted him on board a fisheries research vessel and he was set free outside the harbour. As this was the first day on the job for the newly appointed director, Dr EG Bligh, his dismay, generated by these happenings, led to implementation of stringent rules as to what could and could not be accepted for studies at the Halifax FRB Laboratory (Fig 5).

Fig 5. Viewing the activities related to "Timothy the Turtle". Left to right in the foreground Dr RG Ackman, the scientist in charge of the Marine Oils program, Mr David Horne a scientist from the Fisheries Inspection Service Laboratory, and Dr EG Bligh, the Director of the Halifax Fisheries Research Laboratory on his first day on the job.

Disease Studies

Lobsters and oysters

Work on diseases began in the summer of 1961 when a major and widespread episode of a bacterial infection of lobsters occurred. This infection was caused by a bacterium originally named *Gaffkya homari* [now *Aerococcus viridans* (var.) *homari*], thereby giving rise to the disease name 'gaffkemia'. It had been discovered and described in 1947 in Maine. The causative agent is highly virulent and is a chronic threat to both wild lobsters and more importantly to lobsters held captive in holding units where it can cause serious economic losses i.e. as high as 10% of the lobsters/day. As little was known of the disease other than the identity of the infective agent and as the infection was a major threat to the highly important and profitable live lobster industry, the Halifax FRB Laboratory undertook intensive studies for the purpose of advising on how to avoid the disease and/or develop mitigative measures.

Over a period of more than 20 years, extensive investigations showed the sources of the agent, how it persisted, how it was transmitted (through wounds and breaks in the lobster shells caused by fighting and rough handling), the effects of temperature, salinity and diet, how it caused the deaths of lobsters, and various procedures for dealing with the disease to reduce its occurrence and minimize the severity of the outbreaks. As a result of these studies, it was possible to advise the lobster industry of the effectiveness of using heavy rubber bands rather than wooden plugs to immobilize lobster claws thereby reducing the creation of portals of entry for the bacterium and lessening infection rates. This advice was added to that of the biologists who had been attempting for some time to persuade fishermen to use rubber bands to eliminate shell erosion and blackening of the claw meat. Additional information was provided on diagnostic techniques, antibiotics, use of refrigeration, improved handling, holding and shipping conditions and the development of several vaccines upon which a commercial vaccine was based. These studies provided a number of tools that, when applied, allowed the industry to reduce materially the high losses previously suffered as a result of this disease. Studies were also conducted on a condition of lobsters known as shell disease. Shell disease in the early stages causes unsightly erosions of the shell and in later stages causes the death of the lobsters. Fortunately, neither of these infections affects humans.

In addition to the studies on lobster diseases, work was also begun on an infection of oysters that had destroyed many of the oyster populations in Prince Edward Island starting in 1913 and in New Brunswick and the Northumberland Strait part of Nova Scotia in the mid 1950s. This disease was called Malpeque Disease largely because Malpeque Bay was where the disease was first observed and where the studies were initiated. A great deal of work was done that proved to be helpful to the oyster industry, although it did not result in the identification of the disease causing agent, nor in the elimination of the disease.

Fish

Gradually as more attempts to culture fish were made and more emphasis was placed on maintaining the health of fish in both government and private hatcheries, disease studies at the Halifax FRB Laboratory expanded. Understanding the conditions that led to disease among cultured fish also led to studies comparable to those carried out on shellfish. The already substantial aquarium facilities for live animal work were expanded to accommodate disease studies on both fresh and saltwater species. Thus, increased physical facilities and most importantly a significant increase in well trained and experienced staff allowed fundamental and comprehensive studies on diseases of cultured fish to be undertaken. These were focused on diseases caused by Infectious Pancreatic Necrosis Virus (IPNV), the bacterium *Aeromonas salmonicida* (furunculosis) and *Renibacterium salmonarum* [Bacterial Kidney Disease (BKD)]. In addition to diagnostic studies and field surveys, work was instituted on studies on the modes of pathogenicity of these agents, the means to control them and vaccines to prevent the infections in the first place.

Fish Health Unit

The increasing awareness of aquatic animal diseases in the hatchery systems, fish kills in the wild and in various aquaculture ventures led to requests to diagnose and deal with on-site problems. At first individual scientists dealt with these on an ad hoc basis. As the workload continued to increase it became obvious that a better solution was needed.

Working collaboratively with other scientists across Canada, Halifax FRB staff helped to develop the Fish Health Protection Regulations (FHPR) which were set up to control the inter-provincial movement of salmonid fish coming from sources known to harbour specifically-listed pathogens. This was to prevent the spread of fish diseases from one province to another. A Fish Health Unit was then set up at the Halifax FRB Laboratory to carry out the mandate of the FHPR in the Maritimes. This was a diagnostic unit that certified establishments that wished to export cultured fish or eggs of wild fish. Certification was only given to facilities that could be shown to be free of certain named diseases. For example, salmonids could be imported into Nova Scotia from British Columbia only from facilities that were certified as being free from Infectious Hematopoietic Necrosis Virus (IHN).

The Fish Health Unit was a leader in this field and some of the diagnostic techniques introduced at the Halifax Unit were emulated elsewhere. For example, a stress test that this Unit adapted for improved detection of furunculosis in carrier fish was, in turn, adopted and used by the New Brunswick Department of Aquaculture Diagnostic Laboratory.

Aquaculture Pushes Nutrition Development

The need to understand the dietary requirements of lobsters held captive for varying periods in the lobster trade and the need to improve the diets of farmed fish led to the initiation of nutritional work in 1970. The Aquaculture Section became renowned for its expertise in crustacean nutrition - both in terms of defining nutrient requirements and formulating and producing feeds for both the fishery and the aquaculture industry. While the work was focused principally on the American lobster, the nutritional needs of spiny lobster, freshwater crayfish, and 12 species of penaeid shrimp were also considered. Scientists at the Halifax FRB Laboratory developed standardized methodologies for fish and crustacean nutrition research, and were instrumental in founding the International Working Group on Crustacean Nutrition. In collaborative studies diets formulated at the Halifax FRB Laboratory were tested against more than 30 species of crustaceans in many countries including Japan, Ecuador, France, Tahiti, the United States, Germany, and Sweden.

These studies were extended in 1976 to develop new diets for use in salmon hatcheries. The objective was to improve the rate of return of salmon smolts used in the enhancement programs. Scientists working in the Halifax FRB Laboratory were responsible for kick starting the development of diets for Atlantic salmon in full culture conditions. The salmon feeds that were developed in-house satisfied the dietary requirements of the salmonids and resulted in eliminating a variety of problems. Through a successful technology transfer program, the Halifax Fisheries Laboratory's formulation was produced by private sector feed makers. To a considerable degree, New Brunswick's lucrative cultured salmon industry and that developed in other parts of the world owes much of its success to the work that came out of these studies.

In another application of nutrition research, scientists in the Aquaculture Section developed and supplied a vitamin concentrate pellet for halibut and haddock broodstock. This became necessary because these fish, which had been captured in the wild, did not thrive on the standard dry pellet feeds. The pellet produced as a result of these studies ensured that the eggs would not be deficient in essential vitamins and minerals.

Histology

Utilizing light and electron microscopy, including at one stage one of the first scanning electron microscopes in Canada, scientists working at the Halifax FRB Laboratory studied the musculature and other organ systems of cod, scallop, lobster, oyster and commercially important fish in order to provide a baseline for product quality considerations, nutritional studies as well as comparisons between normal and diseased specimens. Members of this group also wrote four atlases on cod histology used by many scientists working on cod and related species in Canada, Norway and the United States.

Contaminants

From time to time various problems arose for fisheries as a direct result of industrial activities. There were numerous instances of these and all required chemical and/or physiological studies for assessment, detection and/or amelioration. A partial listing would include acid rain, marine algal toxins i.e. domoic acid and Paralytic Shellfish Poisons in shellfish, metals e.g. cadmium and mercury contaminating fisheries products as well as the hazards of materials such as chlorinated hydrocarbons in the marine environment. From among those that arrived at the door of the Halifax FRB Laboratory, two will be sufficient to illustrate the nature of the problems experienced.

Phosphorus

In February 1969, massive concentrations of dead herring were reported piling up on beaches in Placentia Bay in southern Newfoundland. These were described as "red herring" and were being washed ashore to form large windrows; the different occurrences proceeded in an anticlockwise direction around Placentia Bay. This crisis generated an enormous amount of work on the part of FRB scientists in Newfoundland, Nova Scotia and New Brunswick. As a result it was determined that the massive kill of herring was caused as a result of the fish, on their annual spawning migration, swimming through a plume of colloidal elemental phosphorus from a new commercial producer. The fish, depending upon their position in the school, absorbed varying concentrations of the phosphorus. The high concentrations gave rise to petechial bleeding, hence the red coloration and the designation "red herring". As the migration proceeded, the fish which had absorbed the highest concentrations died first followed by those with lesser concentrations. Thus the dead fish washing ashore in huge concentrations traced out the course of their annual spawning migration around Placentia Bay. Thus began a crisis of some eight months duration that consumed a large proportion of the time of FRB scientists, particularly at the Halifax Fisheries Laboratory where much of the analytical work, toxicology studies and direction of the crisis activities took place.

The plume of colloidal phosphorous was coming from Long Harbour where a huge electric reduction plant had begun distilling phosphorus from fluorapatite ore mined in Florida. The distilled phosphorus was condensed and stored under water thereby displacing the water in the condensing tanks. This displaced water was released continuously into Long Harbour and gradually moved through the Harbour out into Placentia Bay. Although most of the elemental phosphorus sank to the bottom of the condensing tanks, the finely divided material (colloid) remained in suspension and was released with the displaced water and provided the toxic effects of the plume.

As the episode had destroyed the herring run and posed a threat to all fisheries in the Bay as well as consumers, the fisheries for all species were

terminated and the phosphorus plant was shut down at once. As a direct result, hundreds of fishermen as well as the employees at the phosphorus plant were thrown out of work. This pollution episode is still the largest and most devastating anthropogenically produced, marine acute toxicity event experienced to date in Atlantic Canada.

Eventually the problem was resolved through a mixture of highly original chemistry, toxicology, clean up, pollution control and expensive compensation programs. Regardless, the conclusion was that if reasonable and informed technical foresight had been applied initially the crisis could have been avoided completely (for the complete story see Jangaard 1972).

Oil spill

The second contaminant issue resulted from the wreck in 1970 of the 'Arrow', a small tanker carrying Bunker C, a heavy fuel oil petroleum fraction. As a result, Chedabucto Bay was badly fouled. The threat to fisheries, fish processing plants and fish quality was considered serious and pressing. Scientists from the Bedford Institute and the Fisheries Research Board were called upon to aid in the declared emergency. Two immediate and basic questions were: what would be the long-term consequences and would the area cleanse itself given time? Studies conducted by Halifax FRB staff showed that hydrocarbon-utilizing microorganisms were plentiful in the area, that their rate of action was governed by temperature and the availability of key nutrients, nitrogen and phosphorus and that the bacteria were capable of cleansing most areas given time. In the meantime, under the direction of the Department of Transport, key areas were cleaned by hand and mechanically; the bulk of the oiled areas was left to clean up through natural processes.

THE FISHERIES RESOURCE BRANCH PROGRAM

Following the termination of the Technological Branch programs in 1978, those elements that remained in the Halifax Fisheries Research Laboratory were already part or became part of the Fisheries Resource Branch responsibilities. The continuing activities of the scientists and sections originally part of the Technological Program have been covered within the first section to avoid confusion.

In the mid 1980s the Invertebrates and Marine Plants Division, previously without laboratory space, moved to the Halifax Fisheries Research Laboratory. They were joined there by elements of the Freshwater and Anadromous Division and some contractors. The remainder of this retrospective covers their sojourn.

The Halifax Fisheries Research Laboratory, as a consequence, became home to several applied research projects which provided scientific advice for the management of economically and socially important invertebrate fisheries: lobster, scallop, shrimp, offshore clams etc, and also marine plants. For example, the successful offshore scallop industry, in particular,

prospered under an Enterprise Allocation system based on knowledge and advice generated by Fisheries Resource Branch scientists.

Harvest Fisheries

The Marine Plants Unit assisted in helping both government and the private sector to assess and manage coastal varieties of seaweeds including Irish moss, rockweed, wire weed and kelp. Remote sensing techniques, including multispectral airborne and satellite-based sensors, were applied bringing these techniques into common usage for the determination of algal standing crops. As a result, *Furcellaria* is now being harvested in western Prince Edward Island, currently yielding up to 700 metric tonnes per year at a value of $800 per tonne. An extract of this marine plant is used as a gelling and emulsifying agent in foodstuffs. In addition, the Unit has developed techniques for rapidly sampling seaweeds and associated organisms, thereby assisting in gaining an understanding as to how the removal of seaweed impacts invertebrates in the ecosystem.

In the early 1980s, staff mapped the occurrence of a disease that killed 270,000 tons of sea urchins along 360 km of the outer coast of Nova Scotia. This sea urchin mortality level, however, heralded a renaissance of the kelp, which grew an additional five million tons per year. In addition, the urchins now no longer interfered with the lobster fishery. By the mid-1990s the urchins had recovered and in a reversal of fisheries interests now supported a lucrative diving fishery, a valuable export industry and renewal of interest in urchin culture by the aquaculture community. Staff was also instrumental in introducing property rights to the sea urchin fishery. In exchange for fishing rights, fishers were required to apply harvesting approaches that were designed to enhance urchin productivity.

Turning underutilized species into harvestable resources is always a worthy challenge, particularly when the seafood in question appears in significant volumes. Because small boats could not use trawl-harvesting methods, pink shrimp were in this underutilized category. The Molluscan Fisheries and Aquaculture Section worked with industry to develop a trap that would enable as few as two fishers to harvest shrimp from a small lobster boat; nine fishers are currently licensed, and six more are scheduled. Using these low operating cost boats, they are averaging five to six pounds per trap and some have 100 traps per license. It is proving to be a lucrative fishery.

Parasitology

Parasitologists at the Halifax Fisheries Laboratory advanced scientific knowledge with regard to seal worms and other parasitic nematodes which grow in the flesh and viscera of marine fish as larvae and mature in the gastrointestinal tract of marine mammals. The research concluded that seal

worms affect more than three dozen species of marine and anadromous fish in eastern Canada including mature Atlantic cod, cusk, monkfish and sea raven. Benthic crustaceans such as mysids and amphipods are important transmitters of the larval seal worm to fish. Not surprisingly, the heaviest infections have been found in fish caught near Sable Island, where the expanding populations of the definitive host, the grey seal, forms its largest breeding concentrations.

As well, scientists at the Halifax Fisheries Research Laboratory published many studies on protozoan parasites of finfish with the demand for more information increasing with the rise in aquaculture. These parasites can multiply more easily in fish farming operations than in the wild. A group of microspora (*Loma* sp.) was recognized and named by Halifax Fisheries Research Laboratory scientists working in conjunction with scientists in the US. This parasite has caused mass mortalities in salmon and trout in Alaska, Scotland and elsewhere, and is causing mortalities of a less severe nature among cultured salmon on the west coast of Canada.

Acid Rain

From the late 1980s until 1997, the Freshwater and Anadromous Division studied the effects of acid rain on salmonids and invertebrates living in rivers and streambeds in Nova Scotia. Low survivability of salmonid eggs occurred under acid rain conditions; unfortunately most invertebrates in the ecosystem, which serve as an essential food source, were similarly impacted. As a result a number of rivers on the Atlantic coast of mainland Nova Scotia have lost their resident populations of Atlantic salmon.

ACCOLADES

On a number of occasions scientists at the Halifax Fisheries Research Laboratory have been singled out for awards for published studies, personal communications and transfer of information and techniques to fisheries and allied interests. A number of these are listed below:

Charles H Castell
Centennial Medal 1967
Earl McFee Memorial Award 1971, Atlantic Fisheries Technological Conference
Public Service Commission Merit Award 1971
Nova Scotian Environmental Award 1985 (Research on Acid Rain)

William J Dyer
Awards from:
United Nations Food and Agriculture Organization

Canadian Institute of Food Science and Technology
Chemical Institute of Canada
Japanese Society of Fisheries
Japanese Society of Heating, Refrigeration and Air Conditioning Engineers

E Graham Bligh and William J Dyer
Citation Classic Award for:
A rapid method of total lipid extraction and purification. Can J Biochem Physiol (1959) 37:911-917

Robert G Ackman
Public Service Commission Merit Award 1979
Member of the Order of Canada 2002
LLD (Hon), Dalhousie University 2003

CONCLUDING REMARKS

It is appropriate that this retrospective appear in the Proceedings of the Nova Scotian Institute of Science, since the Halifax FRB Laboratory and the Institute have enjoyed a close association over the years. Many of the scientists who worked at the Halifax Fisheries Research Laboratory have been members of the Institute, have served on its committees and its Board. The following served as NSIS President: E Hess (1942/43), JR Dingle (1959/60) WJ Dyer (1966/67), RG Ackman (1973/74), PH Odense (1978/79), EG Bligh (1987/88), and JE Stewart (1992-94).

In closing this account it should be stated that the reasons for terminating the Technology Program across Canada included the understanding that the fisheries industry, while gaining much from the program, had now matured and was in a position to look after its own technological needs. It was considered that the industry could do the necessary work in-house or failing that could contract with experimental entities such as the Canadian Institute of Fisheries Technology begun at the Technical University of Nova Scotia (now the Engineering Faculty of Dalhousie University) with transferees from the terminated Fisheries Technology Program. As the buildings at 1707 Lower Water Street had reached the end of their useful lives, they were demolished as soon as alternative accommodation was found to re-locate the remaining activities.

This retrospective has touched upon many of the activities that took place in the Halifax Laboratory and briefly described a number of them. It should also be emphasized that the Halifax Fisheries Research Laboratory had an active educational role. In addition to the transfer of its findings to industry and other agencies already described, it played host to a lengthy list of visiting scientists, post doctoral fellows, graduate students and summer students. Many staff members taught or participated in courses offered at post secondary institutions in and around Halifax. As many of

those visiting or working in the Halifax Laboratory came from other parts of Canada and other countries the sharing of information and scientific cooperation was accelerated greatly and was an extremely important and valuable aspect of the Halifax Laboratory's activities.

The final appraisal of its accomplishments, however, should be left to independent assessors. One, in referring to certain of its activities gave what could serve as a fitting epitaph: "The scientists running the Halifax Fisheries Experimental Station tended to respond positively to requests for these initiatives: fish-processing, research and educational work were probably the greatest contributions to the Atlantic Fisheries made by the Biological Board in the interwar period" (Hubbard 1993).

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BSc Student Biology
Mount Saint Vincent University
for
"Expression of two-pore domain potassium channels in human airway epithelia"

and

Paul Gibbons
BSc Student Biology
Saint Mary's University
for
"The prion"

The Scientific Writing Prize was awarded to:

Gregory W Thiemann
BSc Student Biology
Dalhousie University
for
"Evolution, blood types and weight:
a critical examination of a popular diet"

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2004 NSIS Undergraduate Student Prize Winning Paper: Joint Award

THE PRION

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Transmissible spongiform encephalopathies (TSE) have been documented in livestock for centuries but the nature of the putative causative agent as a contagious, mutant form of a host-encoded protein is a very recent discovery whose nuances remain unclear. In its normal conformation, the Prion is believed to be a short-lived uptake protein ubiquitous in nervous tissues. In contrast, the mutant Prion usually has an identical primary structure, but has a radically different tertiary and quaternary structure that confers on it unusual stability and resistance to the normal post-translational reactions. Most importantly, the mutant protein binds to the normal Prion protein and alters its conformation to the mutant form. Transmission of TSE from host to host has been observed to occur primarily through ingestion of infected tissue and introduction of the mutant Prion to nervous tissue in the mouth, such as the cranial nerves serving the tongue. It is believed that the mutant Prion is transported within the parenchyma via highly motile microglia. The latent damage from eventual accumulation of mutant Prion is the result of the host's immune response to the protein that involves inflammatory TNF-alpha and IL-1 alpha and beta, among others. Clinical symptoms, however, presented well after the host's immune response resulted in spongiform changes to nervous tissue. Fortunately, there currently exists promising research that seeking to explain natural immunity to TSE and apply it to unaffected individuals.

Les encéphalopathies spongiformes transmissibles (EST) sont signalées chez le bétail depuis des siècles, mais la nature de l'agent causal présumé, une forme mutante contagieuse de protéine encodée par l'hôte, est une découverte très récente qui reste mystérieuse sous bien des rapports. Dans sa conformation normale, le prion serait une protéine messagère dont la vie est courte et qui serait très répandue dans les tissus nerveux. Par contre, si le prion mutant a une structure primaire identique, sa structure tertiaire et sa structure quaternaire sont complètement différentes et lui confèrent une stabilité et une résistance inhabituelles aux réactions post-traductionnelles normales. Et ce qui est plus important, la protéine prion mutante se lie à la protéine normale et modifie sa conformation pour la transformer en protéine mutante. On a observé que la transmission des EST d'un hôte à l'autre s'effectue principalement par l'ingestion de tissus infectés et l'introduction du prion mutant dans les tissus nerveux par voie orale, notamment par les nerfs crâniens au niveau de la langue. On croit que le prion est transporté dans le parenchyme par des microglies très mobiles. Les dommages latents d'une accumulation éventuelle du prion résultent de la réaction immunitaire de l'hôte envers la protéine qui fait intervenir le TNF-alpha et les IL-1 alpha et bêta, entre autres. Les symptômes cliniques, toutefois, qui se présentent longtemps après la réaction immunitaire de l'hôte, consistent en des modifications spongiformes au niveau des tissus nerveux. Heureusement, des recherches prometteuses tentent d'expliquer l'immunité naturelle envers les EST et de l'appliquer aux sujets non atteints.

INTRODUCTION

Creutzfeldt & Jakob first described a constellation of symptoms in humans in the 1920's that were subsequently recognized by other clinicians in their own patients. Although very few of these cases would today be classified as Prion diseases, experiments in 1968 established the existence of a transmissible form of the syndrome that became known as Creutzfeldt-Jakob Disease (CJD) (Johnson & Gibbs 1998). Symptoms of CJD were also seen in some New Guinea tribes and were named kuru. Researchers suspected and eventually showed that cannibalistic ritual meals consisting of the uncooked brains of the dead were responsible for these cases of kuru (Harris 1999).

Clinical presentations in humans include dementia, myoclonus (muscle spasms), cortical defects, sensory abnormalities, and seizures, among others; however, only histological tests of brain tissue in suspect cases can confirm Prion disease by revealing spongiform changes characteristic of the transmissible spongiform encephalopathies (Johnson & Gibbs 1998). Accumulation of the putative disease-causing protein, which occurs well before many of the symptoms manifest themselves, is considered to result in neurodegeneration, plaques, vacuoles, and enlarged ventricles (Lewicki et al. 2003). In animals, symptoms have been described in several species for centuries. These include scrapie in sheep and goats, wasting disease in deer and elk, and bovine spongiform encephalopathy (BSE) in cattle, among others (Johnson & Gibbs 1998).

However, the exact nature of the agent of infection remained elusive for some time. As the field of microbiology evolved, microorganisms such as bacteria and viruses were ruled out. Eventually, Prusiner, a researcher at the University of California, concluded that, because the agent resisted treatments that inactivate nucleic acids but was inactivated by those that denature proteins, the infection could only result from a protein (Johnson & Gibbs 1998).

There have been numerous advances in the field of Prion research since Prusiner's initial discoveries: the Prion has been sequenced and its form determined, its life cycle in the cell has been experimentally observed, and the pathogenesis of its mutant variant has been studied. Nevertheless, it should be understood that the field has many unanswered questions. Additionally, the results of existing research need to be confirmed by other investigators before they are used with confidence. Prion researchers are also pressed by public health officials to solve the danger posed by trans-species infection of variant-CJD through the food supply; although preventive recommendations have so far been sound, more sophisticated research involving immunity to transmissible spongiform encephalopathies have been based primarily

on animal models. The use of these results for human applications needs to be approached with care.

The role of the normal Prion protein is subtle, and does not seem to be vital as many examples of individuals in several species exist that do not express any Prion protein at all (Zulianello et al. 2000). The mechanisms of the mutant form of the Prion, however, are not only devastating, but unique in that the mutant protein is itself transmissible (Bartz et al. 2003). Important avenues of research, therefore, include study of the mechanism of host-to-host transmission and of infection within the host, as well as the study of various methods of natural immunity in certain individuals.

THE NATURE OF THE PRION PROTEIN

The normal conformation of the Prion protein, PrP, is ubiquitous throughout the nervous system tissue, though it has been detected in other tissues. It is found in cerebral and spinal neurons and glia, but is concentrated primarily in the neocortex, hippocampus, cerebellar Purkinje cells, and spinal motor neurons (Harris 1999). It is hypothesized that PrP are involved in cellular recognition, signaling, and adhesion because of their location on cell surfaces; however, other experimenters have concluded that PrP facilitates copper or ligand uptake and metabolism (Harris 1999).

Biochemistry of the Prion

An approximately 250 amino acid PrP is synthesized in the rough endoplasmic reticulum (RER), before going through several structural modifications that include the addition of a glycosyl-phosphatidylinositol (GPI) anchor that allows the final protein to attach itself to the cell membrane (Harris 1999). The normal PrP precursor is then cleaved once with a cellular phospholipase to release a signal polypeptide that is attached to the GPI anchor. The PrP is then proteolytically cleaved within its central hydrophobic segment before it is transported to its destination on the cell surface (mostly to the plasma membrane) where it is attached solely by its GPI anchor (Harris 1999). Studies have shown that PrP continuously cycles between its location on the plasma membrane and an endosome (Harris 1999). This cycling is consistent with suggestions that PrP is an uptake protein.

PATHOGENIC PRP

PrP diseases occur in three forms: infectious, sporadic, or familial. In each of these, some mechanism causes the protein to alter its conformation from one that is mostly alpha-helical to one that is mostly

made of beta-sheets (Johnson & Gibbs 1998). Infectious PrP diseases result from the introduction of a conformational isomer of the PrP (denoted here-in and in most literature as PrP^{Sc}) from an outside source, which catalyzes the formation of altered PrP in a self-propagating way. Historically, most PrP infections were iatrogenic, resulting from infected dura mater graft tissue, human pituitary growth hormone, or, more rarely, from improperly sterilized surgical equipment (Johnson & Gibbs 1998). Genetic studies have shown that familiar PrP diseases result from point, line, or insertional mutations on the PrP gene located on chromosome 20, resulting in spontaneous folding into the PrP^{Sc} conformation (Harris 1999). The sporadic PrP diseases, accounting for 80%-90% of all cases in humans, have no apparent etiology to date (Johnson & Gibbs 1998).

Biochemistry of PrP^{Sc}

The methods currently used to determine subcellular location of molecules have tentatively revealed that PrP^{Sc} are extensively distributed within the cell. The plasma membrane-attached PrP^{Sc} are also thought to attach with the GPI anchor, but they cannot be cleaved from the membrane by phosphotidylinositol lipase (PI-PLC), as PrP can (Harris 1999). GPI extracted from PrP^{Sc} was not found to be altered in a way that would confer PI-PLC resistance, and so it is believed that the GPI-anchors on the PrP^{Sc} become sterically inaccessible to the lipase (Harris 1999). The second property that PrP^{Sc} acquires following PI-PLC resistance is its insolubility in detergents; this is thought to represent PrP^{Sc} aggregation of up to 30 PrP^{Sc} units (Harris 1999). The third property of PrP^{Sc} is its protease resistance, thought to be due to PrP^{Sc} polymerization (Harris 1999). These three properties are conferred in distinct and sequential stages. The first, PI-PLC resistance, occurring within minutes of PrP^{Sc} synthesis, is most likely acquired in the RER. Detergent insolubility, which maximizes after one hour of synthesis, and protease resistance, which is seen several hours later, both develop when the PrP^{Sc} are on the plasma membrane (Harris 1999). It has been determined that PrP^{Sc}, having half-lives of 24-48 hours, are much more stable proteins than PrP, which denature in only 4-6 hours. That PrP^{Sc} is formed in the RER is reasonable as that organelle plays a principal role in assisting protein folding. An important consequence of postulating that PrP^{Sc} begin their synthesis in the RER is that, in the infectious cases, the mutant protein must first be carried there to catalyze future conformational changes. Therefore, ER chaperones would act as cellular cofactors to control PrP^{Sc} synthesis. In general, these chaperones attach to their substrates to prevent certain unfavourable intermediary conformations.

Conversion of PrP to PrP^{Sc}

At some point in the pathogenesis of infection from the PrP^{Sc}, an interaction of high physical specificity between the mutant and wild types is believed to take place (Harris 1999). Experimental evidence to support this comes partly from studies of genetically modified mice that do not express any form of PrP and are found to be immune to PrP^{Sc} infection (Harris 1999). Although different strains of PrP^{Sc} exist where each strain is characterized by differences in primary, secondary, or tertiary structures, the most critical location for infection is within the central hydrophobic core between amino acids 94 and 188, which is why interspecies infections are rare (Vorberg et al. 2001). These residues form one alpha-helix and two antiparallel beta-sheets where the alpha-helix binds the mutant PrP^{Sc}, while the beta-sheets precipitate the conformational change (Vorberg et al. 2001). This was seen by engineering PrP that lacked any combination of these three secondary structures, and observing that the conversion of the modified PrP to PrP^{Sc} was greatly diminished (Vorberg et al. 2001). In addition, it was noted that deletion of only the first alpha-helix and the second beta-sheet in this core region affected the cycling of the PrP through the cellular organelles. Predictive models have shown that the first beta-sheet would be responsible for stabilizing an intermediate conformation of PrP^{Sc} (Vorberg et al. 2001). It is this central hydrophobic region of the PrP that is most specific to the species that synthesizes the protein. In fact, even a point mutation in this region can prevent infection. In the cases in which interspecies infection is observed, it is because this region of the PrP is similar enough to allow the necessary interaction (though other regions may not be) (Harris 1999).

The seeded-polymerization model of PrP^{Sc} propagation, which is considered the most likely pathway, requires a seed of aggregate PrP^{Sc} to catalyze new PrP^{Sc} (Vorberg et al. 2001). There is no evidence that PrP^{Sc} covalently differs from PrP because they both have the same amino acid sequence, and mostly similar post-synthesis additions. The most noticeable conformational difference between the two is a drastic increase in beta-sheet, especially in the N-terminus half, at the expense of alpha-helix structures (Harris 1999). Specifically, the PrP tertiary structure has a substantial tail at the N-terminus that is folded, along with a neighbouring alpha-helix, into a beta-sheet.

The hypothesis that different symptoms of Prion diseases represent different conformations of PrP^{Sc} was suggested by comparisons of the resistance to protease-K by a strain that caused hyperactivity (HY), and another that caused drowsiness (DY) in rodents (Scott et al. 1997). However, the diversity of PrP^{Sc} conformations is probably highly limited due to the low variability in primary structure Scott et al. 1997). Figures 1 and 2 show a computer-generated model of the normal and variant forms of the Prion protein (Jackson et al. 1999). Note the unwinding of the three major helices.

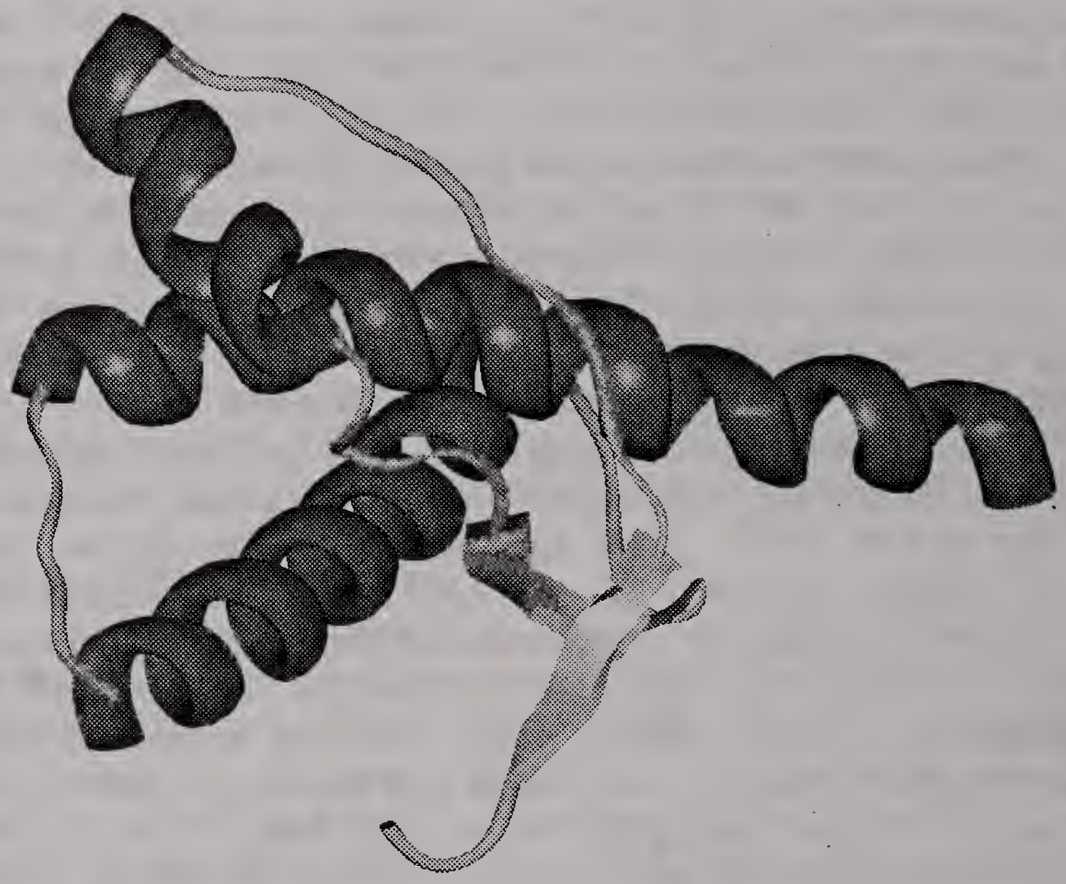

Figure 1 - Normal Prion Structure

Image Credit: http://www.cmpharm.ucsf.edu/cohen/ (used with permission)

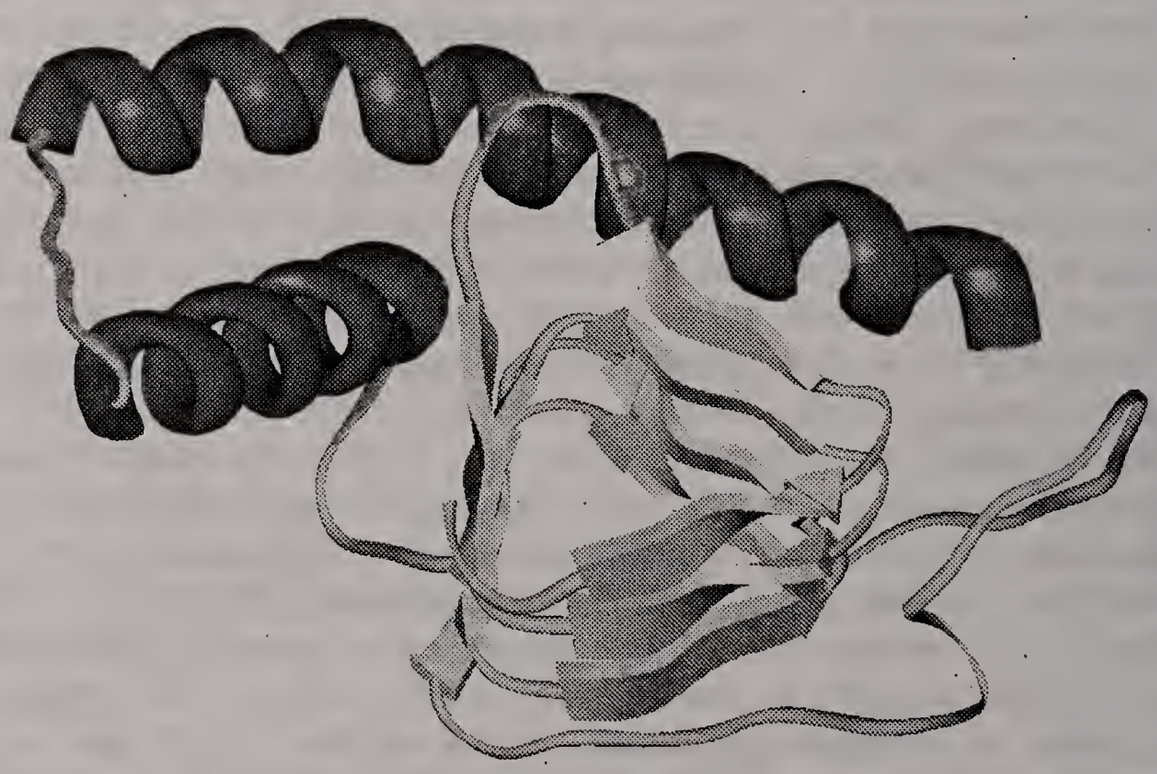

Figure 2 – Mutant Prion Structure

Image Credit: http://www.cmpharm.ucsf.edu/cohen/ (used with permission)

PrP^{Sc} Infection Pathways

Some forms of PrP^{Sc} disease are easily understood: familial Prion disease is genetic and iatrogenic infection occurs following invasive surgeries using infected equipment and materials. Other pathways of infection, such as in kuru, variant CJD, and BSE, have been somewhat more mysterious. This is because these pathways all involve ingesting tissue infected with PrP^{Sc}, sometimes from the same species and sometimes not. The PrP^{Sc} protein will experience not only the very low pH of the stomach, but will also face destruction from gastric pepsin. Recent studies using suitable animal parallels have shown, however, that the primary path of infection is through the cranial nerves serving the tongue, the enteric nervous system, and the abdominal lymphatic system (Bartz et al. 2003). In cases of ingestion of tissue infected with PrP^{Sc}, the most effective path of infection starts from the skeletal muscle in the tongue, proceeds up the hypoglossal nerve (CN XII), transsynaptically spreads to the vagus nerve (CN X), and finally infects the brain stem from the dorsal motor nucleus of the vagus nerve (Bartz et al. 2003). Because PrP are found in subsynaptic areas on the nerve cell, entry is most likely to occur at the neuromuscular junction on the tongue. The presence of terminal nerve endings exposed by other infections, cuts, or scrapes in the mouth and on the tongue increases the rate of propagation and likelihood of infection of PrP^{Sc} (Bartz et al. 2003). It has been shown that PrP^{Sc} can replicate and accumulate in individual axons on the tongue during early stages of infection. As the infection progresses, the PrP^{Sc} are observed in the nucleus of the vagus nerve (CN X), and in the motoneurons of CN XII (Bartz et al. 2003). Additionally, it has been observed that intracranial infection will spread peripherally along the same pathways and end up in the tongue, both on the nerves and on the skeletal muscle (Bartz et al. 2003). Secondary infection can spread through the lymphoreticular system, and concentrate in lymph organs such as the spleen (Bartz et al. 2003). Alternate pathways from oral ingestion are through the trigeminal nerve (CN V) and the glossopharyngeal nerve (CN IX) or through the facial nerve (CN VII) and the glossopharyngeal nerve (CN IX) (Bartz et al. 2003).

Although Prions are primarily associated with neural cells, the infectious PrP^{Sc} have been identified in circulating leukocytes that have never directly contacted infected neurons. Therefore, it was postulated and shown that PrP^{Sc} can be carried by microglia (Baker et al. 2003). Microglia are the macrophages of the nervous system, and are myeloid in nature. Damage to the brain, through diseases such as Alzheimer's and CJD, or injury, will activate microglia, causing them to alter their morphology. Experimental limitations have not permitted researchers to determine if microglia support PrP^{Sc} replication, but mathematical models that account for their actual level of infectivity suggest that they do

(Baker et al. 2003). Further, it is postulated that microglia are only one type of cell in a network that are responsible for the widespread distribution of the infection (Baker et al. 2003). PrP^{Sc} may be able to take advantage of the high motility of microglia within the parenchyma to move from cells with lower replication to those with higher potential. In this respect, PrP^{Sc} mimic viral pathways of infection that invade myeloid cells and remain dormant until they accumulate in numbers significant enough to cause structural brain damage (Baker et al. 2003).

Immune Response to PrP^{Sc}

As the amounts of PrP^{Sc} increase in the brain and central nervous system, there is an immune response that involves CD4 and CD8 T-lymphocytes, major histocompatibility complex (MHC) I and II molecules, and chemokines (Lewicki et al. 2003). As the PrP^{Sc} progress, the genes that activate tumor necrosis factor alpha (TNF-alpha), interleukin-1 alpha and beta are expressed in the central nervous system (Lewicki et al. 2003). TNF-alpha is an inflammatory mediator that has many functions including increasing the expression of MHC class I receptors on endothelial cells and causing fever; IL-1 alpha and beta are also pyrogens, affect sleep, and cause anorexia, inflammation, and lymphocyte activation, among other functions. Chemokines, which induce chemotaxis of T-cells and natural killer cells, are produced from infected astrocytes and neurons. These responses of the immune system were always observed to occur well before clinical symptoms of PrP^{Sc} appeared, both in animal experiments and in human subjects (Lewicki et al. 2003). The infection outside the central nervous system is thought to activate the T-cells, which can cross the blood-brain barrier only in this form. Perhaps simultaneously, chemokines of CNS origin attract the activated T-cells. In certain studies that measured the effect of CD4 and CD8 T-cells on the course of PrP^{Sc} disease, it was found that removal of either had no effect at all, but removal of both drastically delayed the onset of symptoms (Lewicki et al. 2003).

An unknown protein denoted in the literature as Protein X assists conformational change between PrP and PrP^{Sc}; changes in the primary structure of Protein X will hinder the onset of PrP^{Sc} disease (Zulianello et al. 2003). Four critical residues, 167, 171, 214, and 218, have been identified on the PrP that prevent its conversion to PrP^{Sc}, should any of them be changed to a basic amino acid. These changes, which cause PrP to bind more tightly to Protein X, are effective only in certain combinations, and were found to have reduced inhibition of PrP^{Sc} formation if they are compounded (Zulianello et al. 2003). In animals and humans that are naturally resistant to PrP^{Sc} diseases, the phenotype that expresses this modified PrP has been found to be responsible. It was determined that protection from PrP^{Sc} diseases is the result of dominant-negative inhibition where those with a single allele that encodes for PrP have immunity (Zulianello et al. 2003). The knowledge of the mechanism

of this natural immunity as it relates to the interaction of PrP with Protein X suggests that pharmacological treatment for PrP^{Sc} may lie in its successful imitation.

CONCLUDING REMARKS

The Prion protein, when it acquires its correct tertiary and quaternary structure in the RER, performs such a subtle role within the cell that it goes entirely unnoticed: even a definitive consensus of its main function remains elusive. It is only when the Prion is misfolded that its effects become felt. Herders of certain breeds, such as cows, goats, and sheep, have left for posterity their descriptions of inexplicable blights upon their livestock that we can now retrospectively guess were transmissible spongiform encephalopathies. People have also been infected through surgeries, grafts, and cannibalism, and suffered the consequent neurodysfunction. The work of .Prusiner to identify the agent of this disease, not as a virus or a bacterium, but as a protein, resulted in a series of questions about the Prion that are still being investigated, and recently with added vigour as the economic and public health issues surrounding BSE and variant CJD become more pressing. Despite its pathogenicity, this author believes that PrP^{Sc} exhibits wondrous elegance in its ability to catalyze its own self-replication *in vivo* using healthy PrP as a source.

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EVOLUTION, BLOOD TYPES, AND WEIGHT LOSS: A CRITICAL EXAMINATION OF A POPULAR DIET

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In a best-selling diet book D'Adamo & Whitney (1996) claim that an individual's ABO blood type is the single most important factor in determining the appropriate diet for weight-loss and general health. This is based on the premise that the four different blood types have evolved within the past 50,000 years and that each type is an adaptation to a particular lifestyle and diet. While each of the four recommended diets, if followed for an extended period, would likely produce weight-loss in people suffering from obesity, modern genetic research indicates that the human ABO blood groups evolved millions of years ago and pre-date the existence of *Homo sapiens*. With no clinical evidence or theoretical basis to support them, the claims for the supposed curative functions of D'Adamo & Whitney's Blood Type Diet are misleading and potentially dangerous.

Dans leur livre de régime à succès, D'Adamo et Whitney (1996) allèguent que c'est le groupe sanguin d'une personne qui est le facteur le plus important dans le choix d'un régime approprié pour maigrir et rester en santé. Cette affirmation est basée sur l'hypothèse que les quatre groupes sanguins ont évolué au cours des 50 000 dernières années et que chacun résulte d'une adaptation à un style de vie et à un régime particuliers. Les quatre régimes recommandés, s'ils étaient suivis pendant une période prolongée, seraient certes de nature à faire maigrir les personnes qui souffrent d'obésité, mais les recherches en génétiques actuelles indiquent que les groupes sanguins humains ont évolués depuis des millions d'années et remontent même avant l'existence de l'*Homo sapiens*. En l'absence de preuve clinique ou de fondement théorique pour les appuyer, les allégations relatives aux soi-disant fonctions curatives des régimes de D'Adamo et Whitney basés sur le groupe sanguin sont trompeuses et peuvent même s'avérer dangereuses.

INTRODUCTION

Diet book publishing has become a multi-billion dollar industry, with successful titles spending more than six years on the New York Times bestseller list. At the same time, obesity has reached epidemic proportions in North America, affecting 27% of the U.S. population, with an additional 34% considered overweight (Wyatt 2003). Although obesity in Canada is less widespread (approximately 15% in 1998) it more than doubled from 1985 to 1998 (Katzmarzyk 2002). The health implications of epidemic obesity are serious, leading to increased rates of diabetes,

heart disease, and 280,000 deaths each year in the United States alone (Allison et al. 1999). With promises of miraculous weight-loss and renewed vitality, diet books have become extremely popular in a North American society struggling to lose weight.

One of the best-selling diet books is 'Eat Right 4 Your Type: The Individualized Diet Solution to Staying Healthy, Living Longer and Achieving Your Ideal Weight' by D'Adamo & Whitney (1996). In it the authors claim that each blood type (A, B, O, or AB) is an adaptation to a particular lifestyle and diet. A person's blood type determines what they should eat, how they should exercise, their susceptibility to illness, and how they react to stress. D'Adamo & Whitney assert that "*your blood type is the key that unlocks the door to the mysteries of health, disease, longevity, physical vitality, and emotional strength*". 'Eat Right 4 Your Type' is the first volume in a 16 book series; among the most recent titles are 'Cancer: Fight it with the Blood Type Diet' (D'Adamo & Whitney 2004) and 'Diabetes: Fight it with the Blood Type Diet' (D'Adamo & Whitney 2005). With such ambitious claims, a detailed examination of the theory behind these books is both appropriate and necessary.

THE BLOOD TYPE DIET THEORY

According to 'Eat Right 4 Your Type', the human blood types evolved in response to changes in the ancient human habitat and diet. Consequently, each type is perfectly suited to the particular diet most common at the time and place the blood type emerged. The book asserts that the ABO blood types appeared sequentially as humans evolved and dispersed across the globe. Type O appeared in the earliest humans in Africa about 50,000 years ago; Type A appeared as humans moved away from hunter-gatherer lifestyles and towards agrarian society (15,000-25,000 years ago); Type B evolved as humans migrated into colder environments in Europe, Asia, and the Americas (10,000-15,000 years ago); and Type AB was the product of interbreeding between populations of Type As and Bs (about 1000 years ago).

According to 'Eat Right 4 Your Type', Cro-Magnons of 40,000 B.C. were skilled hunters who relied on animal protein for their nutritional requirements. While the authors refer to these early peoples as hunter-gatherers, they indicate that Cro-Magnons relied solely on meat and their Type O blood was specialized for digesting animal protein; however, it should be noted that the authors fail to explain how blood types can modify digestion. Apparently, these early humans occupied the top of their African food chain and their population eventually "exploded". Within 10,000 years, competition for limited food resources became intense and people started fighting for territory; "*as always, human beings found their greatest enemy to be themselves*". Around 30,000 B.C., as a result of this intense resource competition, people began to

migrate out of Africa to Europe and Asia. People were as gluttonous in these areas as they were in Africa, and by about 20,000 B.C. the vast herds of large animals in these new lands had been decimated. It was apparently at this point that humans finally began to utilize plants as food: "*it is likely that the carnivorous humans quickly became omnivorous, with a mixed diet of berries, grubs, nuts, roots, and small mammals*". The northward migration of early humans also "*created lighter skins, less massive bone structures, and straighter hair*" than in the African population. Eventually, the Cro-Magnons overpopulated their northern hunting grounds as well and either went extinct or migrated further to the Americas.

Considering this evolutionary backdrop, D'Adamo & Whitney (1996) instruct modern Type Os to also consume a meat-based diet. "*Eat beef, lamb, turkey, chicken or the recommended fish as often as you wish. The more stressful your job or demanding your exercise program, the higher the grade of protein you should eat*". Unfortunately, the meaning of "grade of protein" is not explained. D'Adamo & Whitney do recommend that Type Os try to limit portion sizes—not to aid digestion or avoid heart disease, but because "*our ancestors didn't feast on sixteen-ounce steaks; meat was too precious and scarce for that*". However, this seems entirely inconsistent as large portion size was likely a common characteristic of early meat-based diets. The concept of food storage depended on the development of agriculture and animals killed by Cro-Magnons therefore had to be consumed more or less immediately or left to rot.

In addition to a high-protein, high-fat, high-calorie diet, Type Os should avoid cereals, breads, grains, pasta, dairy products, and even many vegetables such as cabbage, corn, and brussels sprouts. Surprisingly, even condiments, spices, and beverages should be carefully considered. For instance, mustard is fine, but ketchup is harmful to Type Os. Cayenne pepper is also good, but black pepper should be avoided. Beer and wine is acceptable, but Type Os should stay away from tea and soft drinks.

'Eat Right 4 Your Type' also recommends evolutionarily-compatible exercises. Type Os "*have the immediate and physical response of our hunter ancestors*," and "*are meant to release the built-up hormonal forces through vigorous and intense physical exercise*". D'Adamo & Whitney (1996) therefore recommend one or more of the following activities, three to four times per week: aerobics, swimming, jogging, stair climbing, martial arts, and contact sports.

Evidently, Type Os tend to be "*strong, certain, and powerful—blushing with good health and optimism*". D'Adamo & Whitney (1996) cite Ronald Regan as a stereotypical Type O: "*His administration was characterized by a surety, evenness, and an unflagging optimism about the future*". Other notable Type Os include, Al Capone, Mikhail

Gorbachev, Queen Elizabeth II, and disgraced sports commentator Jimmy "The Greek" Snyder.

Blood group A apparently emerged with the rise of agriculture and permanent farming communities in Asia and the Middle-East, later migrating into western Europe. With their largely vegetable-based diets, the Type A mutation allowed Neolithic people "*to better tolerate and absorb cultivated grains and other agricultural products*". With the rise of permanent human settlements, " *planning and networking became the order of the day. Psychologically, these are the traits at which Type As excel*". D'Adamo & Whitney (1996) claim that the Type A phenotype quickly spread through the farming population. "*What could have been the reason for this extraordinary rate of human mutation from Type O to Type A? It was survival. Survival of the fittest in a crowded society. Because Type A emerged as more resistant to infections common to densely populated areas, urban, industrialized societies quickly became Type A*". Here, the authors have not only seriously confused the concepts of genetic mutation and natural selection, but also suggested that the industrial revolution played a role in evolutionary changes that presumably occurred 20,000 years ago.

'Eat Right 4 Your Type' recommends a vegetarian, low-fat, low-calorie diet for Type As. They should avoid meat, dairy, most wheat and fish, and some fruits and vegetables, including bananas, oranges, cabbage, eggplant, and lima beans. In addition to these severe dietary restrictions, the unfortunate Type A is also predisposed to heart disease, cancer, and diabetes. The Type A exercise program involves soothing and non-strenuous exercises such as tai-chi, yoga, and golf. These activities presumably help Type As calm down since they "*tend to have more tightly wired systems. They bottle up their anxiety...but when they explode, watch out.*" Also, "*Type As are poorly suited for the intense, highly pressured leadership positions at which Type Os excel...[w]hen Type As get into these positions, they tend to unravel*". Perhaps not surprisingly then, the list of notable Type As is substantially less admirable than Type O; Lyndon B. Johnson, Richard Nixon, Jimmy Carter, and Adolph Hitler round out the list. D'Adamo & Whitney (1996) even contend that Hitler's actions were consistent with "*a mutated Type A personality*".

The remaining two diets are along the same lines as the first two. Briefly, the book claims blood Type B evolved independently of Type A 10,000-15,000 years ago in what is now Pakistan and India. In the cold Himalayan environment, "*blood Type B may have initially mutated in response to climactic* [sic] *changes*". Type Bs have a tolerant digestive system and should eat a balanced, nutritious diet. They have strong immune systems, should engage in lots of medium intensity exercise, and tend to have creative and well-balanced personalities.

Blood group AB apparently emerged about 1000 years ago as a result of interbreeding between Type A Europeans and Type B

"*barbarian hordes*" from Asia. While it seems odd that Type AB didn't emerge until very recently despite the coexistence of Types A and B for at least 10,000 years, D'Adamo & Whitney (1996) base their timeline on the fact that "*prehistoric graves in Hungary show a distinct lack of this blood group*". It would be interesting to know precisely how many graves were examined considering that blood group AB is quite rare in the modern human population; i.e., only 3% of Canadians are Type AB (Canadian Blood Services 2004).

The Type AB diet is the most complicated and arbitrary of the four, with seemingly random contributions from both the A and B programs. People with AB blood should engage in similar exercise as Type As (non-strenuous) but "*are often stronger and more active than the more sedentary Type As*". Type ABs tend to be charming, popular, spiritual, but "*somewhat flaky*" and evidently have exceptionally weak immune systems. Some famous Type ABs include John F. Kennedy, Marilyn Monroe, and apparently Benedict Arnold. Unfortunately, no information is provided as to how Arnold's blood type was determined; he died exactly 100 years before the ABO classification system was devised.

DOES THE BLOOD TYPE DIET WORK?

The reasoning behind the Blood Type Diet is clearly a creative, if somewhat rambling story. The diets themselves are enthusiastically defended by followers who swear that the system "works." It seems likely that any of the four diets, if maintained over an extended period, would encourage weight-loss, since each one prescribes reasonable portion sizes and lots of exercise.

Close to 90% of the North American population would be instructed to follow either the Type O or the Type A diet. The Type O plan is the kind of low-carbohydrate diet that Samaha et al. (2003) showed could result in weight loss of about 5 kg over a six-month period in severely obese people. The authors, however, also noted a dropout rate of 47%. The Type A diet is simply a low-calorie, vegetarian diet and if anyone following it could also manage the recommended five sessions of aerobics each week, weight-loss would also be likely. While a strategy of controlled caloric intake and regular exercise is the only reasonable weight-loss strategy, the evolutionary theory upon which the Blood Type Diet is based is seriously flawed.

Blood Type Biology and Evolution

The ABO blood groups were discovered in 1901 by Nobel laureate Karl Landsteiner. Humans and other primates can be typed according to the ABO system: Type A blood contains red blood cells (RBCs) with the A antigen (a protein) on their surfaces, Type B cells have the B antigen,

Type AB cells have both A and B antigens, and Type O RBCs have neither. In addition, blood contains antibodies opposite to the existing antigens (i.e., Type A blood contains anti-B antibodies, Type B blood contains anti-A antibodies, Type O blood has both kinds of antibodies, and Type AB has neither). ABO blood type is controlled by alleles at a single gene locus on chromosome 9.

The entire Blood Type Diet theory rests on the idea that the two blood type antigens (A and B) and the four different phenotypes evolved sequentially in the human population over a period of about 50,000 years. The authors claim that in this way, each blood type became perfectly adapted to the dominant diet at the time of its emergence. However, it is important to note that blood cells contain hundreds of other antigens in addition to A and B and more than 20 other blood typing systems have been developed (see Garratty et al. 2000). Why the ABO classification system should hold such a special place in our evolutionary history is not addressed in 'Eat Right 4 Your Type'.

If diet and blood chemistry were as tightly coupled as D'Adamo & Whitney (1996) claim, and considering the enormous regional and cultural variation in human diets, one could reasonably expect far more than four blood phenotypes to emerge. Furthermore, species with more narrow and specialized diets should be expected to have fewer blood types, although this does not seem to be the case. Wild cats are obligate carnivores and show three different blood types (A, B, and AB; see Griot-Wenk & Giger 1999) while horses have 14 different blood group phenotypes and a strictly herbivorous diet (Dobrev et al. 1972).

D'Adamo & Whitney (1996) have based their unique theory of human evolution on the modern geographic distribution of blood types. The A allele is most common in Europe and the Near-East, the B allele is most common in southern and central Asia, and (within the Old World) Type O is most common in Africa (Mourant et al. 1976). These correspond to the areas where 'Eat Right 4 Your Type' claims the three blood types originated.

D'Adamo & Whitney (1996) also confuse correlation with causation when speculating that the development of agriculture resulted in the evolution of blood type A. While there is a relatively high frequency of Type A in the same general region of the Near-East where agriculture originated (Renfrew 1973, Diamond 1999), there is no evidence to suggest that this is the time or place where humans first utilized plant material or where blood type A emerged. To the contrary, an overwhelming body of evidence indicates both omnivory and the ABO blood types pre-date agriculture by millions of years.

D'Adamo & Whitney's (1996) theory ignores the fact that the evolutionary ancestors of all modern primates were forest-dwelling creatures that fed on insects as well as fruits, nuts, berries, and other plant material (Morris 1967). Our ape ancestors depended on vegetation long before they came down from the trees and learned to hunt. The

dentition of modern primates reflects this omnivorous past, with pointed canines and sharp incisors suitable for tearing meat, combined with flat, grinding molars and thick enamel for crushing tough plant cell walls (e.g. Shellis et al. 1998). In fact, plant material comprises 87-99% of the annual diet of all great apes (Milton 2003). In our more recent past, the fossil record indicates the closest direct ancestors of *Homo* spp. (*Australopithecus* sp.) were also omnivores, roughly two to four million years before agriculture (e.g. Robinson 1954, Wood & Strait 2004). D'Adamo & Whitney's assertion that humans were strict carnivores prior to the development of agriculture completely ignores the fossil record.

Recent genetic studies have provided a fascinating insight into blood type origins. A-like and B-like antigens are present in the blood of several non-human primates; A in chimpanzees, B in gorillas and siamangs, and both A and B in orangutans, gibbons, and New and Old World monkeys (O'hUigin et al. 1997 and references therein). The evolutionary relationship of human blood antigens to those of non-human primates has been the subject of recent debate. Martinko and his colleagues (Martinko et al. 1993) concluded that the A and B alleles were so similar in all primates that they must have come from a common ancestor. These authors estimated that the polymorphism responsible for the two alleles was at least 13 million years old. The various blood types therefore evolved before humans, chimps, or gorillas. In a separate study, Colm O'hUigin and his colleagues at the Max Planck Institute for Biology (O'hUigin et al. 1997) found that between primate species, the A, B, and O alleles were indeed very similar, but were more likely the result of convergent evolution, not a common ancestor. These authors estimated that the human blood type lineage emerged at least three million years ago. Whether the blood groups are the result of convergent or trans-species evolution, it is clear that they not only pre-date agriculture and urbanization, they pre-date the existence of *Homo* spp. (Wood & Collard 1999, Wood 2002).

How the Blood Type Diet is Supposed to Work

The Blood Type Diet offers a mechanism that is relatively vague and not easily examined in detail. D'Adamo & Whitney (1996) contend that food interacts with a person's blood via lectins—a broad class of proteins found in nearly every living organism and characterized simply by an ability to bind to carbohydrates. According to the Blood Type Diet, these proteins react to blood cells in a type-specific way and cause them to agglutinate, or clump together. Once ingested, different lectins apparently target specific organs and physiological systems and eventually lead to conditions as serious as schizophrenia, cancer, and strokes. In order to prevent this toxic agglutination, 'Eat Right 4 Your Type' instructs readers to avoid foods with lectins that are "incompatible" with their blood type. The incredible danger of food lectins is illustrated

with a description of ricin, "*a toxic lectin extracted from castor beans*" and a poison made infamous by a KGB assassin in 1978. (In a peculiar coincidence, ricin was also cited by the Bush administration as one of the "weapons of mass destruction" controlled by Saddam Hussein (CIA 2002)).

Research on lectins has revealed a remarkably diverse group of proteins (more than 100 have been isolated from legumes alone (Sharon & Lis 2002)) with correspondingly diverse biochemical properties. While some lectins potentially can agglutinate red blood cells, those found in most food items are inactivated by heating and only the raw; mature beans of the genus *Phaseolus* (e.g. lima bean, kidney bean, black bean) have sufficient levels of lectins to cause untoward reactions (Liener 1986, Sharon & Lis 1989, 2002). Even those lectins that cause blood cell agglutination are not necessarily harmful. In fact, the toxicity of ricin is caused by the inactivation of ribosomes, not RBC agglutination. The agglutination observed during early studies was not caused by the ricin lectin, but rather by another compound called RCA (*Ricinus communis* agglutinin), which is nontoxic (Olsnes et al. 1974, Rüdiger & Gabius 2002).

Origins of the Blood Type Diet

D'Adamo & Whitney (1996) claim that two pieces of evidence were instrumental in developing their diet theory. The first was the observation that peptic ulcers were more common in people with type O blood. The second piece of evidence was that both pernicious anemia and stomach cancer were more common in Type As. From these two observations, D'Adamo & Whitney conclude that "*there absolutely was a scientific basis*" for a blood type-based diet since there was a connection between blood type and gastric disease.

In making this conclusion, D'Adamo & Whitney (1996) again confuse correlation with causation. Just because stomach cancer is statistically more common in Type As than Type Os does not mean that Type A blood causes cancer, or that "incompatible" foods cause cancer. Furthermore, while real correlations may exist between ABO blood groups and certain diseases (e.g. Norwalk virus (Hutson et al. 2002)), the relationships cited by D'Adamo & Whitney are not well-supported by evidence.

Increased rates of pernicious anemia in Type As and peptic ulcers in Type Os were recorded in the mid-1950s (e.g. Buckwalter et al. 1956, Creger & Sortor 1956), but more recent studies failed to corroborate these findings (e.g. Callender et al. 1957). Carmel et al. (1981) found no relationship between blood type and pernicious anemia among African- and Latin-American patients, and questioned the accuracy of the apparent association between blood type A and gastric cancer. Further, the majority of peptic ulcers are now thought to be caused by the

bacterium *Helicobacter pylori* (or by extended use of non-steroidal anti-inflammatory drugs) and recent studies have shown no association between blood type and *H. pylori* infection or the incidence of peptic ulcers (e.g. Umlauft et al. 1996, Keller et al. 2002, Robertson et al. 2003).

While the book claims to be "*an extension of the recent groundbreaking findings concerning human DNA*", it relies heavily on literature from the 1950s and 1960s. Although the book was originally published in 1996, only eight of the 103 cited references were published after 1990, and three of those eight were either authored or co-authored by D'Adamo himself. The book cites two notable papers by Wyman & Boyd (1935, 1937) regarding the evolution of blood types. These authors considered the rate of human genetic mutation and concluded that the ABO blood types were at least 750,000 years old—some 700,000 years older than D'Adamo and Whitney (1996) claim. Wyman & Boyd also concluded that for the B blood type to have evolved within the last 20,000-50,000 years, the human mutation rate would have to be so high that it would exceed the rate of mutation in *Drosophila*—an unrealistic assumption. D'Adamo & Whitney appear to have twisted the work of Wyman and Boyd to fit their hypothesis: "*The genetic mutation that produced Type A from Type O occurred rapidly—so rapidly that the rate of mutation was comparable to four times that of* Drosophila*, the common fruit fly and current record holder!*"

CONCLUSIONS

The four "individualized" diets offered in 'Eat Right 4 Your Type' all recommend limited caloric intake combined with lots of exercise. As a result, each one, if followed over an extended period, would probably promote weight-loss. Unfortunately, the severe and arbitrary food-choice restrictions likely make adherence to any of the diets exceedingly difficult. Despite this potential for weight-loss—and D'Adamo & Whitney's (1996) assertions to the contrary—the Blood Type Diet theory has no basis in evolutionary biology, anthropology, or biochemistry.

One could argue that the theory behind any diet is less important than the results it produces. However, when any popular book claims to be based on "scientific research", it must be challenged—not only to protect the non-scientific reader from dubious claims, but also to protect the credibility of real science. 'Eat Right 4 Your Type' not only offers easy answers for weight-loss, but also for disease therapy. D'Adamo & Whitney (1996) insist that the Blood Type Diet will not only *prevent* certain diseases (it is reasonable to suggest a vegetarian diet could reduce the risk of heart disease), it will also *cure* them. The last two chapters of the book are dedicated to case histories of "patients", most of whom were apparently treated by D'Adamo alone, who were cured of

everything from arthritis and psoriasis to breast cancer and AIDS. With no clinical or theoretical evidence to support them, these claims are misleading and potentially dangerous to people suffering from serious illness.

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Volume 43, Part 1, pp. 69-74

NOVA SCOTIAN INSTITUTE OF SCIENCE

SESSION 2003-2004

President's Report

During this past year the Institute presented a varied program of public lectures. All were held at the Nova Scotia Museum of Natural History, except for one evening, where the staff at the Discovery Centre hosted us and demonstrated some of their programs. Topics of the seven presentations covered a range of scientific disciplines. Attendance was generally good, and several meetings attracted capacity audiences due in part to the fact that the Museum now lists our public lectures in its Events Calendar. We thank the Museum for that, as well as its continuing financial support of our activities.

The Institute also sponsored its second annual student paper competition. Thirteen entries were received, up from six in last year's inaugural competition. The papers were generally of high calibre, and four prizes were awarded. The winners were Frank MacMaster (of Dalhousie - a Graduate award), Kellie Davis (of Mount Saint Vincent - an Undergraduate award), Paul Gibbons (of Saint Mary's - an Undergraduate award) and Greg Thiemann (of Dalhousie - a Science Writing award). Our judging panel consisted of Carolyn Bird, Susan Bjornson, Jonathan Blay, Stuart Grossert, Duane Guernsey (Pathology) and Jana Sawynok (Pharmacology). Their efforts were greatly appreciated. Special thanks go to Jonathan Blay, who very efficiently coordinated the entire project.

Over the year we updated our membership list, and conducted a special campaign to collect membership dues. Thanks go to Membership Chair Georgia Pe-Piper and Treasurer Stephen Ewart for all their work.

Council discussed various approaches to increasing student membership. A new initiative arising from these discussions was a Mentorship Program, where Institute members were to be asked to volunteer to act as mentors to undergraduate and graduate students. A request has gone out recently to all members, and I encourage everyone to take part in this program. Special thanks for developing this initiative go to a Council sub-committee, consisting of Dena Simon, Georgia Pe-Piper, Andrew Hamilton, Jonathan Blay, and Sean Tibbetts. Sean has kindly offered to act as Chair of this program.

Thanks to the continuing efforts of Surjit Verma, the Institute has again supported a number of Regional Science Fairs. This year we supported six Fairs, as well as the BIO Showcase for Regional winners.

Details of the publication of the Proceedings, and the maintenance of the Institute's Library will be presented in the Editor's and Librarian's Reports. I do want to acknowledge with thanks the work of Jim Stewart as Editor, and Sharon Longard as Institute Librarian. I want to express my gratitude to our two student representatives on Council - Andrew Hamilton, who also served as our Webmaster this year, and Derek Schnare. My thanks go as well to Calum Ewing of the Nova Scotia Museum and Dena Simon of Discovery Centre for all their help.

In closing, I want to express my sincere appreciation to all members of Council for their participation in ensuring another successful year. My special thanks go to our Secretary, Truman Layton, Past-President, Jonathan Blay, and Vice-President, Carolyn Bird. These three individuals have made my job as President a pleasure.

Finally, I thank the membership for the opportunity to serve as Institute President.

Presented to the AGM
May 3, 2004
Archie McCulloch
President NSIS

Appendix: Lectures and Panel Discussions

October 6: *Surviving extreme physiological stress: molecular chaperone function during development of Artemia embryos.*
Tom MacRae, Department of Biology, Dalhousie University

November 3: *Cancer control in Nova Scotia: The Model... The Program... The Outcome.*
Andrew Padmos, Commissioner, Cancer Care Nova Scotia

December 1: *...the coolest place to play and learn ... Discovery Centre's approach to science education.*
Dena Simon, Director of Operations, Discovery Centre
Terry Roberts, Program Coordinator, Discovery Centre

Januarv 5: *Sleep - what it can do for you*
Ben Rusak, Departments of Psychiatry and Psychology, Dalhousie University

Februarv 2: *Composting in Halifax Regional Municipality*
Jeff Traver, Miller Waste Systems

March 1: *Mussel monitoring: the good, the bad and the safe supply*
Shawna MacKinnon, Institute for Marine Biosciences, NRC.

April 5: *Underwater observations of novel behaviour in the Greenland shark, Somniosus microcephalus*
Chris Harvey-Clark, University Veterinarian, Dalhousie University

Mav 3: *The evolution of electrotherapy and its introduction into Nova Scotia in the nineteenth century*
Allan Marble, Dept Electrical and Computer Engineering, Dalhousie University
Annual Dinner Speaker

Librarian's Report

There are currently one hundred and ninety-one NSIS exchange partners. This number is down by one trom the previous year, reflecting the cancellation of journal exchange by Iowa State University. The number of institutional members remains stable at twenty-seven. Invoices were sent out in February 2004 for institutional memberships and nineteen have renewed so far.

No issue of the Proceedings of the Nova Scotian Institute of Science was published during the past year so there was no mailing to exchange partners or institutional members.

The Flora of Nova Scotia by A.E. Roland continues to sell @ $15.00, and approximately thirty copies were sold during the past year. The Bras d'Or Lakes issue of the Proceedings (volume 42, part 1,2002) also continues to sell @ $22.00/issue, with a recent order for twenty-five copies filled in April.

The ongoing project of adding records to Novanet for those NSIS journal titles that are no longer received but have back volumes in storage has come to a temporary standstill due to the December 2003 retirement of Alison McNair, the Special Projects librarian in Killam Library. Many thanks to Alison for all her efforts to make this material accessible.

Publications continue to be received regularly from our 191 active exchange partners and this material is added on an ongoing basis to the collection. I would like to thank Carol Richardson and the Serials Department staff in the Killam Library who ensure that the NSIS Library operations continue to function smoothly.

Respectfully submitted to the AGM
May 3, 2004
Sharon Longard
NSIS Librarian

Editor's Report

1) The Proceedings of the Nova Scotian Institute of Science [The Oceanography of the Bras d'Or Lakes: B. Petrie, Guest Editor] distributed in 2003 continued to draw interest. As all of the extra 220 copies of the issue had been sold by the time of the 2003 AGM, a further 200 copies were printed in the summer of 2003. Approximately 80 of the additional print run have been sold.

2) The second half of Volume 42 is almost ready for printing. The final adjustments to the galleys are being made and it is anticipated that the issue will be printed by mid-May 2004. This issue consists of 13 papers on Environment and Biodiversity (M. Willison, Guest Editor), two NSIS Graduate Student Prize papers (T. Estabrooks, Biology Department, St. Mary's University and B. Kaur, Faculty of Engineering, Dalhousie University) plus the reporting of NSIS affairs.

3) Work is well advanced on the next issue which is expected to be complete and distributed in the NSIS 2004-2005 program year. It will contain among other materials a written symposium on marine sciences, student papers and a report on NSIS affairs.

   It is anticipated that the issue following this will be ready by the summer of 2005 and will carry review articles concerning northern corals.

Respectfully submitted to the AGM
May 3, 2004
James E. Stewart
Editor NSIS

Treasurer's Report

ASSETS:	
Bank Account	$12,358.98
Petty Cash	0.00
	12,358.98
Investments	48,843.39
Account Receivable	61,202.37
61,202.37	
LIABILITIES AND NET WORTH:	
Accounts Payable	0.00
Total Liabilities and Net Worth	61.202.37

INVESTMENTS:	
Cash Balance	1,400.00
CIBC Premium T-Bill (short-term)	9,047.39
CIBC Investment Certificate A @4.40% (due Apr 2008)	8,396.00
Citizens Bank Certificate A @3.60% (due Feb 2006)	10,000.00
MTC GIC @5.20% (due May 2004)	10,000.00
National Trust GIC @5.20% (due May 2005)	10,000.00
	48,843.39

Membership
147 Members - 131 regular, 12 student, and 4 life members

note: Net Worth 2003 (AGM) - $58,933.56

Respectfully submitted to the AGM
May 3, 2004
H. Stephen Ewart
Treasurer

Instructions to Authors

The *Proceedings of the Nova Scotian Institute of Science* publishes papers in English or French. Manuscripts must be typewritten double-spaced with 4 cm margins. Disk copies in Word or WordPerfect are preferred, but must also be accompanied by three paper copies of the manuscript. An abstract of no more than 200 words, free of formulae, must be included at the beginning of the paper, followed by key words or phrases. This should be followed by an introduction, methods, results or observations, discussion and references. In some cases a combination of these sections may be more effective. Underline only material to be set in italics, and use capital letters only when the letters or words should appear in capitals in the printed paper. Layout and style should follow that used in recent volumes. Each page of the manuscript should be numbered, the first page carrying only the title, authors' names and affiliations and any necessary footnotes. Spelling should follow that of Webster's Third New International Dictionary. Abbreviations, nomenclature, and symbols for units of measurements should follow international recommendations. SI units should be used whenever possible. Use day-month-year sequence for dates. Do not use periods after abbreviations. Photographs should be mounted on Bristol board ready for reproduction. Prints must be of high quality on glossy paper with no space between those mounted in groups. Color illustrations will be accepted at the discretion of the Editor. The cost of color reproduction is borne fully by the authors who must submit a statement accepting this responsibility. References are to be collected at the end of the paper and referred to in the text by inclusion of the author's name and year of publication. Please abbreviate journal titles according to 'BIOSIS Serial Sources', latest edition, and adhere closely to PNSIS format (see the following examples).

Periodicals	Nielsen KJ, Franz DR (1995) The influence of adult conspecific and shore level on recruitment of the ribbed mussel *Geukensia demissa* (Dillwyn). J Exp Mar Biol Ecol 188:89-98
Books	Cushing D, Walsh J (1976) The ecology of the seas. WB Saunders Company, Toronto
Papers from books or symposium proceedings	Lee GF (1975) Role of hydrous metal oxides in the transport of heavy metals in the environment. In: Krenkel PA (ed) Heavy metals in the aquatic environment. Pergamon, Oxford, p 137-147
Pers. comm.	Smith AJ (2001) (Nova Scotia Department of Agriculture, Halifax) Personal communication

Tables should be numbered consecutively in bold-faced Arabic numerals and must have brief titles that are self-explanatory; each table must be typed on a separate page.

Illustrations are to be numbered consecutively in Arabic numerals. Captions should be self-explanatory and typed on a separate page. Two paper copies of each are required even when they are embedded in an electronic file. All lines in drawings must be of suitable thickness to reproduce well when published in the *Proceedings*. Similarly, letters and symbols in drawings should be at least 2 mm high when reduced to the size used in the *Proceedings*.

Page Charges. Currently a charge of $25 per page is levied to help defray the cost of publication. This amount is charged to the institution or a contract supporting the research reported in the published paper. In no case will acceptance of the paper be dependent upon payment of the page charges.

Authors are responsible for editing the galley proofs. Orders for reprints, in addition to the 15 supplied gratis to the corresponding author, must be received when the galley proof is returned.

Papers should be sent to the Editor:

JE Stewart, Department of Fisheries & Oceans
Bedford Institute of Oceanography, PO Box 1006
Dartmouth, NS, Canada B2Y 4A2
E-mail: stewartje@mar.dfo-mpo.gc.ca

Recommandations aux auteurs

Le *Proceedings of the Nova Scotian Institute of Science* publie des articles en anglais ou en français. Les documents soumis doivent être dactylographiés à double interligne avec des marges de 4 cm. On préfère recevoir le texte sur disquette en format de traitement de mot Word ou WordPerfect ainsi que trois copies imprimées. Au début de l'article, on exige un résumé n'excédant pas 200 mots, sans formules et suivi de mots ou d'expressions clés. Cette partie devrait être suivie par l'introduction, les méthodes, les résultats ou observations, la discussion et les références bibliographiques. En certain cas, il sera peut-être plus efficace de combiner quelques parties. Soulignez seulement ce qui devrait paraître en caractères italiques et écrivez avec une majuscule seulement ce qui devrait être imprimé en majuscule. Les détails de présentation et de style devraient suivre un numéro récent de la publication. Chaque page de l'article devrait être numérotée et la première page ne portera que le titre, les noms d'auteurs, leurs adresses respectives et toute note infrapaginale qui s'imposera. L'orthographe doit suivre *Le Grand Robert* et les accents doivent être insérés sur les majuscules. Les abréviations, la nomenclature et les symboles seront conforme aux recommandations internationales. Où possible, utilisez le Système international d'unités. N'ajoutez pas de point aux abréviations. Les photographies devraient être montées sur une carte Bristol prêtes à reproduire. Les épreuves doivent être de qualité supérieure et aucune espace devrait séparée une collage d'un groupe de photographies. Les illustrations en couleurs seront acceptées comme l'éditeur scientifique jugera à propos. Les coûts de reproduction en couleurs seront aux frais des auteurs qui devront émettre une déclaration acceptant cette responsabilité. Les références bibliographiques devraient paraître à la fin de l'article et devraient être citées dans le texte à l'aide des noms d'auteurs et de l'année de publication. Veuillez, s'il vous plait, abréger les titres des journaux selon le 'BIOSIS Serial Source', dernière édition, et respecter strictement le format PNSIS (voir les exemples suivants).

Périodiques	Nielsen KJ, Franz DR (1995) The influence of adult conspecific and shore level on recruitment of the ribbed mussel *Geukensia demissa* (Dillwyn). J Exp Mar Biol Ecol 188: 89-98
Livres	Cushing D, Walsh J (1976) The ecology of the seas. WB Saunders Company, Toronto
Articles de livres ou de compte rendu	Lee GF (1975) Role of hydrous metal oxides in the transport of heavy metals in the environment. In: Krenkel PA (ed) Heavy metals in the aquatic environment. Pergamon, Oxford, p 137-147
Communication personnelle	Smith AJ (2001) (Nova Scotia Department of Agriculture, Halifax) Personal communication

Les tableaux doivent être numérotés de façon continue en chiffres arabes et en caractères gras. Chacun doit comporter un bref titre qui s'explique de soi même et doit être dactylographié sur une page distincte.

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Frais de publication. Des frais de 25,00 $ par page sont présentement imposés afin de subvenir une portion des frais de publication. Ce montant est imputé à l'institution ou au contrat qui appuie la recherche présentée dans l'article. L'acceptation de l'article pour publication ne reposera jamais sur le paiement des frais de publication.

Les auteurs sont responsables pour la revue des épreuves en placard. On doit recevoir les commandes pour des tirés à part, en plus des 15 qui sont fournies gratuitement à l'auteur correspondant(e) , quand vous retournerez les épreuves à placard.

Soumettez vos articles à l'editeur scientifique:
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The Nova Scotian Institute of Science

- The Nova Scotian Institute of Science was formed in 1862 from the Halifax Mechanics Institute (1831-1860) and the Halifax Literary and Scientific Society (1839-1862) making it one of the oldest learned societies in Canada.
- Among the Institute's roles are the stimulation of scientific research and provision of scientific information to scientists and the general public through meetings and publication of the Proceedings of the Nova Scotian Institute of Science. The Institute provides scientists, technologists, educators and administrators with an opportunity to communicate with each other and to the community through public lectures, panel discussions, its Proceedings and the Internet.
- The Institute has a library, established in 1864, now housed in the Killam Library at Dalhousie University; it has a number of periodicals not available elsewhere in Canada.
- Prominent members of the scientific community are invited to address the Institute at a series of regular meetings held on the first Monday of each month from October to May. The lectures and panel discussions are free and open to the public; the topics are of broad interest. The meetings take place usually at the Nova Scotia Museum of Natural History, 1747 Summer Street, Halifax at 7:30 PM. For topics, meeting locations and more information on the Institute please consult the NSIS website:
  http://www.chebucto.ns.ca/Science/NSIS
- Membership in the Institute is open to anyone with an interest in science. Information on joining can be obtained from the NSIS website and Council members.

2005-2006

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Proceedings of the Nova Scotian Institute of Science

Sponsored by the Nova Scotian Institute of Science and supported in part by a grant from the Nova Scotia Museum, the Proceedings produces one or more issues per year and will consider for publication original articles principally, but not exclusively, in the areas of natural and engineering sciences as well as papers emanating from studies in the health professions. Papers that develop new scientific theories based on scientific principles and/or analysis of data particular to Nova Scotia or the Atlantic Provinces are especially encouraged.

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Volume 43, Part 2, pp. 75-90

GENERAL INTRODUCTION: MARINE SCIENCE ESSAYS

JAMES E. STEWART
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Dartmouth, Nova Scotia B2Y 4A2

In 2012, the Bedford Institute of Oceanography will celebrate its 50th anniversary. Such a landmark is an appropriate time for the Institute to take stock, consider its past and debate the course or courses that should be pursued in the future. To aid such an examination it was decided that a written symposium, in which a number of key fields in Marine Science were described and analysed, would give a clear picture of the fundamentals of these fields and demonstrate why they should be of concern and interest to the average person as well as to the scientists involved.

These thoughts are now presented in this published set of 5 articles prepared by distinguished senior scientists currently associated with the Bedford Institute in full time or emeritus positions. Apart from the General Introduction the articles cover the fields of:

1) Marine Geology
2) Physical Oceanography
3) Biological Oceanography
4) Fisheries Science
5) Marine Ecosystems Assessment

In these several articles the authors provide information on historical and background events and attempt to answer such questions as:

1) What is involved in acquiring the relevant information?
2) What can be done with the information?
3) Where are these various fields headed (nationally and internationally) and where in the writers' opinions should they be headed?
4) What benefits can be derived by following the courses advocated and what penalties accrue by not following them?

A useful beginning can be made, by illustrating the importance of marine areas to Canada and the scale of marine sciences needed, through a summary description of the marine areas associated with the Canadian land mass. This land mass totals 9.97 million square kilometres (km^2) fronting on 3 quite diverse oceans, the Pacific, Arctic and Atlantic. In accordance with

E-mail: stewartje@mar.dfo-mpo.gc.ca

the 1982 United Nations (UN) Convention on the Law of the Sea (LOSC) Canada's jurisdiction over its adjacent marine areas consists of the 200 nautical mile (nm) Exclusive Economic Zone (EEZ) that includes a 12 nm territorial sea and a 24 nm contiguous zone for a total of 4.62 million km^2. In addition, Article 76 of the LOSC provides for defining and claiming "extensions to offshore areas beyond 200 nm where coastal nations with wide continental margins may exercise sovereign rights over mineral and certain biological resources, and also wield a measure of jurisdiction in matters related to environment and conservation. With wide continental margins on its eastern and northern coasts Canada has an opportunity under the terms of the Convention to support national jurisdiction and authority beyond the 200 nm limits in the Atlantic and Arctic Oceans. The total area potentially could equal that of Canada's three prairie provinces" (Macnab 1994).

Provisional calculations based upon existing information suggest that the total size of the area beyond the 200 nm limit claimable by Canada could add another 1.76 million km^2 to the offshore areas. The 4.62 million km^2 within the EEZ plus the possible claimable 1.76 million km^2 outside the 200 nm limit totals 6.38 million km^2, an area equal to 64% of the 9.97 million km^2 Canadian land mass (see Fig 1). Claims for all

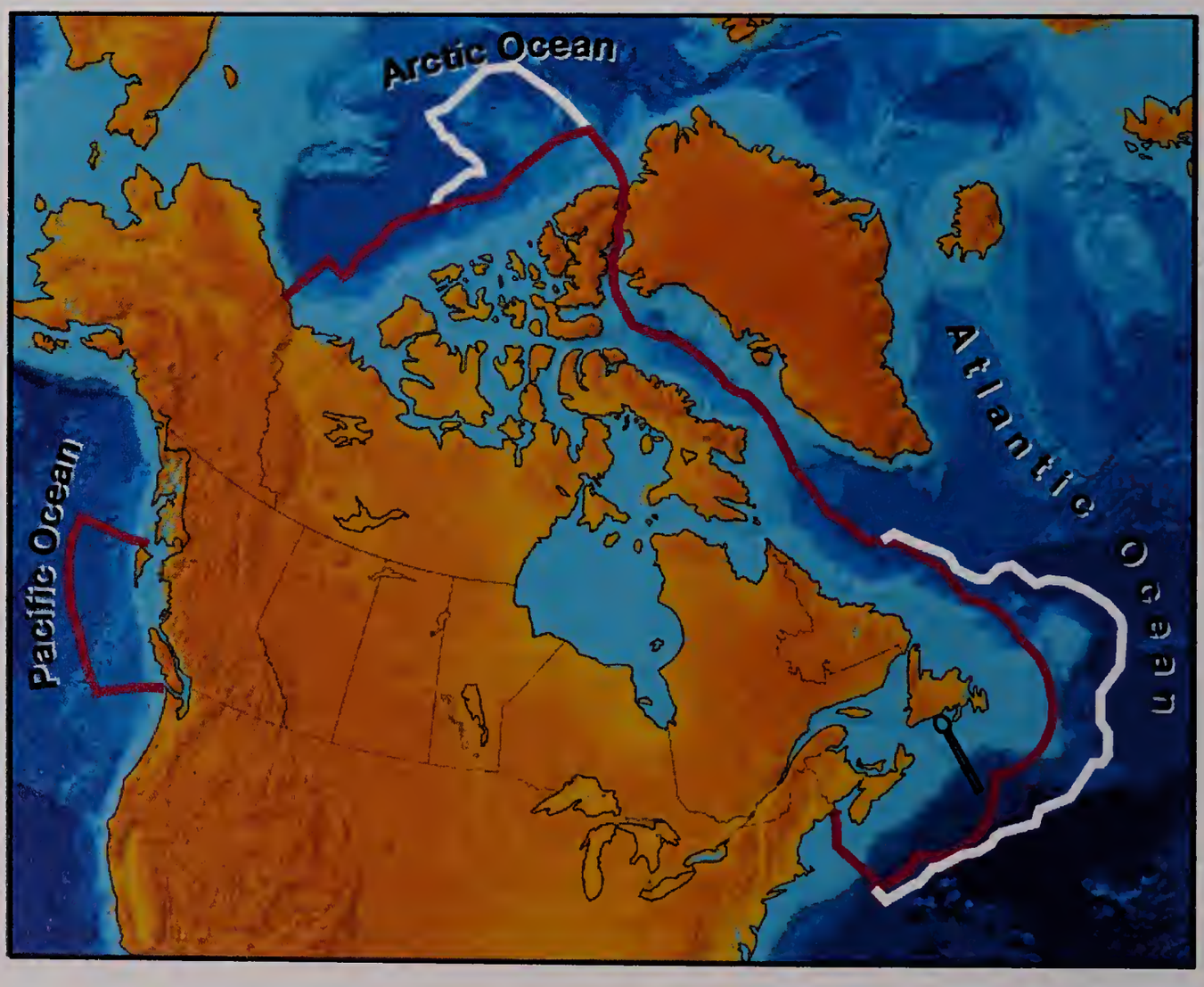

Fig 1 Map of Canada illustrating the 200 nautical mile limit outlined in red (i.e. the Exclusive Economic Zone) and the potentially claimable areas outlined in white. The French Zone south of Newfoundland is rendered in black (redrawn from Macnab 1994).

of the areas outside the 200 nm limit, of course, must be supported by specific, accurate and highly detailed data assembled, analysed and submitted within 10 years of the date notification of a claim is filed. All of these possible claimable marine areas encompass regions that have considerable potential for minerals including gas, oil, and gas hydrates; exploitable fisheries, however, are confined with numerous restrictions to bottom dwelling species. The overriding need will be to explore, evaluate and assess the potential.

In addition to the physical and biological attributes of the total marine areas, it will be necessary to determine how the systems interact and relate to Canadians' every day life through exercising marked influences over weather and climate which in turn govern agriculture, fisheries, mineral extractions etc. Canada's approach regarding this enormous marine area is best discerned in the preamble to Bill C-26, an Act respecting the Oceans of Canada promulgated in 1997. This Oceans Act laid the foundation for an integrated and balanced national oceans policy framework supported by regional management and implementation strategies. The Preamble to the Oceans Act has been summarized as follows (Herbert 1999):

- Canada promotes the understanding of ocean processes, marine resources and marine ecosystems to foster sustainable development of the oceans.
- Canada holds that conservation, based on an ecosystem approach is of fundamental importance to maintaining biological diversity and productivity in the marine environment.
- Canada promotes the wide application of the precautionary approach to the conservation, management and exploitation of marine resources in order to protect these resources and preserve the marine environment.
- Canada promotes the integrated management of oceans and their resources.
- Under the Oceans Act the lead role is given to the Department of Fisheries and Oceans (DFO) and directs "The Minister (of DFO) in collaboration with other ministers, boards and agencies of the Government of Canada, with provincial and territorial governments and with affected aboriginal organizations, coastal communities and other persons and bodies ..... Shall lead and facilitate the development and implementation of a national strategy for the management of estuarine, coastal and marine ecosystems".

Thus the National Oceans Strategy as directed by the Oceans Act is based on the principles of sustainable development, integrated management, and the precautionary approach to decision making.

As part of the development of a comprehensive strategy for integrated ocean management intended to serve during the 21st century, the following issue areas have been identified (Herbert 1999):

- Understanding Our Oceans
- Conserving Oceans Biodiversity
- Marine Environmental Quality
- Shipping and Maritime Safety
- Integrated Planning and Management
- Ocean Industries and Related Opportunities
- Aboriginal Issues
- Arctic Issues
- Maritime Safety and Enforcement
- International Considerations
- Public and Community Awareness and Participation

To provide the databases upon which such a strategy can be developed will require immense efforts by the many people participating in the multiple disciplines and agencies involved with marine affairs. Although no one body, agency or discipline will be able to provide everything that is required, each group bearing significant or particular responsibilities, must know its role and how it relates to the whole. In addition, it is obvious that only through the best efforts of private ventures, academic institutions and governmental agencies working in combination will the requisite information bases be made available to adequately underpin a comprehensive strategy. In this set of essays, we have attempted to examine in some depth the history and accomplishments in several areas relevant to the overall requirements that are or can be conducted by facilities such as the Bedford Institute of Oceanography and its associated laboratory, the St Andrews Biological Station, that are mandated to investigate important areas in the marine sciences. In addition to their strengths as institutes engaged in in-depth scientific studies, as parts of a government agency they also bring specific, unique built-in capacities and responsibilities i.e.:

- Relatively rapid responses to emergencies
- Continuity
- Archiving
- Responsibilities for specified official international interactions and collaborations

Although part of the impetus for this written symposium is to provide sound documentation for discussions concerning programming at BIO and St Andrews specifically, the debate will immediately and inevitably draw in and upon studies at other institutions locally and abroad. Not only should the discussions and debates range widely, but also they should recognize an underlying urgency. In this regard, it is impossible to function in the marine sciences these days without being made aware, almost on a daily basis, of the threats, from many sources, to the well being of the marine and freshwater ecosystems and environments.

One of the most comprehensive and balanced reports available on this topic is the 522-page report prepared in 2004 by the United States Commission on Ocean Policy entitled "An Ocean Blueprint for the 21st Century". In examining the total benefits which accrue to the US from the entire ocean, coasts and Great Lakes, the Commission concluded "the contribution swells to over $4.5 trillion, fully half the nation's gross domestic product ....." The report goes on to state that "Unfortunately, our use and enjoyment of the ocean and its resources have come with costs, and we are only now discovering the full extent of the consequences of our actions." In its earlier preliminary report, the commission stated that it had found "among other things, depleted resources, over-exploitation of many fish stocks, lost habitat, decreased resiliency of ocean and coastal ecosystems and pervasive water contamination problems". The Commission chairman went on to state, "Fundamentally, the message we heard boiled down to this: the oceans and coasts are in trouble and we need to change the way we manage them. Perhaps most important, people must grasp the vital role oceans play in their lives and livelihoods and the profound impact they, themselves, have on the oceans and coasts. What's now obvious is that ocean resources are not limitless. Nor are ocean waters capable of continual self-cleansing. We can create an improved policy that balances use with sustainability, is based on sound science and educational excellence .....". The report puts forward over 200 recommendations affecting items ranging from upstream areas to the depths of the sea, from practical problem solving to broad guidance for ocean policy. The report, although concerned with ocean matters directly connected to US interests, has a high degree of relevance and commonality for all coastal states. The urgency expressed in the report and many of the approaches advocated also are of immediate importance to all coastal states.

THE ESSAYS ON MARINE SCIENCES

Marine Geology

This essay is presented first as the decision was made arbitrarily to begin with the more physical approaches moving through to the more biological. The authors, as would be expected, begin with an historical account and then move rapidly to cataloguing the issues past and present, and complete their account with an in-depth consideration of the coming decade.

As they emphasize, understanding the geological framework and geological processes is necessary for safe and sustainable management of seabed resources. Although ravages of beach mining largely have been halted, the number of people in the coastal zone continues to grow resulting in more causeways, bridges, docks, marinas and shoreline protection structures which affect the stability of the coastline. They point out that not only is there a need to predict the consequences of storms, but also the impacts of the continuing rise of the sea itself, both exacerbated by global warming.

The two priorities they foresee for government marine geoscience are: 1) sea bed mapping for ocean management, including safe and sustainable use of natural resources; and 2) societal responses in the coastal zone to natural hazards, global climate change and anthropogenic pressures including environmental degradation. In addition, much of the burden for exploring and preparing inventories in the areas claimed beyond the 200 nm limit will be placed on the geosciences.

Delivering these programs will require a strong, integrated Canadian science program (involving universities, industry and government) in the history of glaciation, sediment transport, numerical modelling especially of coastal zone changes, estuarine studies and increasingly multidisciplinary approaches. New tools will be required; research vessels, greatly increased remote sensing, autonomous underwater vehicles, improved high resolution seismic equipment and seafloor camera systems, and improved methods to deal with the rapidly accumulating masses of data. In addition, an often-overlooked element will be the need to maintain and strengthen links with the international marine geoscience community in order to fill numerous gaps in the Canadian marine geoscience program.

Physical Oceanography

It is generally agreed that the beginning of this field as a science dates from the *Challenger* Expedition of 1872-1876. As noted in this essay, Halifax was the first port of call for the *Challenger* after it had occupied a series of oceanographic stations across the North Atlantic in the crossing from England. Early oceanographic expeditions yielded a broad description of the physical, chemical and biological distributions in the oceans, but were not able to delineate the processes that governed those distributions. The development of the theoretical basis for the dynamics of the oceans and the atmosphere was pioneered at the beginning of the 20th century by Scandinavian oceanographers and meteorologists.

In fact, it was the leading Norwegian marine scientist, Johan Hjort, who supervised the first systematic physical oceanographic survey in Atlantic Canada. Dr. Hjort, on the basis of his studies in Norway, was invited by the Canadian Government to lead the 1914-1915 Canadian Fisheries Expedition. The results of this demonstration expedition were so impressive that throughout the 1920s and '30s this work was continued in Atlantic Canada especially by the staff of the St. Andrews Biological Station.

Physical oceanography, over its first century plus, has developed the theoretical understanding as well as the observational, analytical and modelling tools to design and operate ocean observing systems that can deliver reliable information from the open ocean, shelf seas and inshore environments. Beginning as a science devoted largely to supply information to navigators and improve safety at sea, it has become a sophisticated endeavour that can stand alone in resolving important questions. These questions range from the role of the oceans as major determinants of climate and weather to the flow of nutrients within the oceanic bodies which

determine to a large extent the variations in the productivity of large areas of the ocean e.g. the immense anchovy fishery off Peru governed by such elements as the El Niño Southern Oscillation.

This essay also offers the opportunity to consider the comments made by Sverdrup (1955) who stated that, "physical oceanography is in the unique position of being independent of the other marine sciences while serving as an auxiliary science to these".

As described herein, physical oceanography is an applied science upon which many other scientific enterprises depend. Although the need for co-operation with other branches of science was recognized from the outset, it unfortunately has not always happened. In discussing this topic Sverdrup pleads that, "the necessity of cooperation between marine scientists cannot be expressed too often". He attributes the failure to achieve this essential level of cooperation to a lack of breadth in training for all sciences and particularly between physical oceanographers and marine biologists, "perhaps because they have difficulty in talking in terms which are mutually understood". To a considerable extent the overall thrust in the various essays illustrates the degree to which the admonitions of leading scientists such as Sverdrup and Bigelow (cited by Sverdrup 1955) have been taken to heart and applied.

Biological Oceanography

It is clear from the contents of this essay that the advice offered by Sverdrup (1955) on the need of marine scientists to broaden their training so as to enhance mutual understanding has been heard and applied. Attention is drawn to the broad range of biological oceanography by citing a course description that includes the topics of marine microbial ecology, phytoplankton ecology and marine primary productivity, zooplankton ecology, benthic ecology etc. The case is made that the field is extremely diversified and consists of such an amalgam of transformations of chemical components mediated by biological systems that the far broader term "biogeochemistry" might be a more appropriate descriptor than "biological oceanography".

Biological oceanography has been reviewed comprehensively and an analysis is given of the progress made in Canada since a major review by Parsons (1975). Although multi-disciplinary projects are now more the rule than the exception and much progress has been made, large numbers of key issues remain unresolved. Prominent among these is the characterization and understanding of the various food webs and the influence on them of anthropogenic interventions (i.e. fishing and pollution) in relation to the planktonic and benthic ecosystems which are the fundamental basis of overall productivity of the oceanic biota. The importance of this information to overall fisheries success is emphasized also in the subsequent essays in this series.

The essay leaves the reader with three major questions for the future drawn from a major oceanographic report:

1) What controls the time-varying biogeochemical state of the ocean and how will it respond to global change?
2) How will the marine food webs respond to and force global change?
3) How does carbon accumulation in the ocean as well as the release of carbon dioxide and methane respond to global change?

These key questions raise issues that in addition to those already enunciated include the following:

- What are the roles of physical and chemical drivers in determining marine food web structures and functioning?
- What are the relations among biodiversity, structure, function and stability of marine ecosystems?
- How do variations in marine food webs manifest themselves over various time and space scales?
- What is the effect of climate variability on the ocean's biological pump (i.e. carbon sequestration in the deep ocean mediated by ocean biota)?

Finally it should be noted that biological oceanography is rapidly evolving through the advent and exploitation of new technologies on the macro-scale (e.g. satellite remote-sensing) and micro-scale (e.g. genomics). It is apparent that this application of molecular tools, in particular, is fostering the development and adoption of a new field in biological oceanography i.e. microbial oceanography.

History of Marine Fisheries Science

Fisheries science is defined as biological research on factors controlling the production of aquatic species of possible or established commercial importance and estimation of their yield potential. The key role of science is to define the biological bounds within which the social and economic benefits of fishing can be pursued.

Although the roots of fisheries science in Canada date back to 1898, it was not until after the Second World War that significant efforts concerned with rational exploitation of the fish stocks were made. As a consequence, the main focus of this paper is placed on post 1950 events and the important demersal (goundfish) fisheries of that period: Atlantic cod, haddock, redfish and flatfish.

The introduction of the factory-equipped freezer stern trawler in 1954 revolutionized the fishery in the Northwest Atlantic and around the world. This type of vessel combined the more efficient stern trawling with on-board filleting machinery and frozen storage. This removed the constraint placed on distant-water fishing that had limited the trip periods to the 7-9 days that fish could be preserved on ice. Other technological improvements opened the way for diversified high volume fisheries and a consequent doubling of Northwest Atlantic catches in the 1960s.

By the early 1970s these increased extractions resulted in a virtual collapse of the demersal fishery and a crisis in the Canadian fisheries. The Canadian fisheries were salvaged by a combination of two events. The first was the direct financial intervention in the industry by the Canadian Government. The second was that discussions at the Third United Nations Conference on the Law of the Sea had reached a stage whereby nations felt they were in a position to declare 200 nautical mile fisheries zones. Thus Canada extended its jurisdiction over most of the fishing banks off its coast in 1977. Some important fishing areas, however, e.g. the nose and tail of the Grand Banks and Flemish Cap lay outside the new limits and required continued arrangements for international fisheries management. A new international convention came into effect in 1979 and the Northwest Atlantic Fisheries Organization (NAFO) was formed to meet this need.

With the extension of jurisdiction, Canada adopted an objective of "best use" defined in terms of net social benefits to be achieved by direct national control of the fisheries guided by annual management plans prepared with scientific advice derived from fisheries assessments and evaluations. These actions plus the earlier experiences with the NAFO predecessor, the International Commission on Northwest Atlantic Fisheries (ICNAF), led to a formalized and sophisticated fisheries data collection and assessment system to support the preparation of the annual management plan.

Ironically, despite the institution of an elaborate and comprehensive fisheries management system based upon annual scientific advice, the composition of the Canadian Atlantic landings was altered materially. What had been an east coast fishery sustained by demersal fish (mainly Atlantic cod) forming approximately 80% of the landings in the 1950s had by the 1990s become fisheries in which invertebrates (lobster, scallop, shrimp, crabs etc.) formed more than 50% of the landings and a substantially higher percentage of the value. Specifically, the reason for this major alteration in landings was the collapse of many of the demersal stocks, particularly in the northern areas.

As would be expected with this dramatic and relatively abrupt major dislocation in the extensive fisheries of Atlantic Canada came demands for explanations as to how such a transformation could have happened. Unfortunately for such a complex event, no clear single, simple answer could be produced. Even today, there are still many unanswered questions and continuing debates with arguments descending into recriminations and accusations of all kinds, about the respective roles of fisheries and environmental change. In this essay the authors have laid out in a balanced manner a clear exposition of the sequence of events that led to this catastrophe. The examination includes frank evaluations of assumptions, conclusions drawn from these, acknowledgement of mistakes made and shortcomings in fisheries science, fisheries management and the fisheries with a candid analysis of the factual data upon which the various arguments are based. Sadly, as the collapse of major fisheries around the world clearly shows, applications of identical and/or similar approaches did not avoid equally disastrous results elsewhere.

The conclusions drawn from the prolonged controversy over the collapse of the groundfish stocks "emphasizes the need for a return to a broader based fisheries science that puts fish stocks in the context of their ecosystem" (Halliday & Fanning 2006). As a constructive way forward the authors suggest altered approaches and inclusion of additional institutional arrangements, including an operations research function, that they believe are essential to achieve success in fisheries management.

Marine Ecosystem Assessment

In this final essay, the initial and guiding premise is, "The collapse of major fish stocks around the world and their failure to recover even after the cessation of fishing and the perceived deficiencies in single species fisheries management has resulted in an intensified interest in the study of whole systems". Using more than 60 data series dating back to 1970 and beyond, an integrated analysis of biotic, abiotic and human variables was conducted and produced an assessment of the current state of the ecosystem of the Eastern Scotian Shelf relative to its past.

Profound changes in community composition and size distribution over the approximately 30-year period were noted. The major ecosystem changes were examined in light of important changes in the area's ocean climate. The consequences recorded show a dramatic change over the past decade with small-bodied species such as sand lance, capelin and herring becoming prominent. The most notable changes observed were shorter generation times, increased mortality levels, increased population variability and decreased bioenergetic efficiencies. Importantly, it was also discovered that the natural mortality levels for cod and haddock are 2-5 times higher than previously assumed.

Taken as a body the study is revolutionary in concept and in results. Read in conjunction with the previous essay on the History of Fisheries Science it reveals a hitherto unsuspected dynamism in the interaction of various species with each other and their fluctuating physical environment. Only through in-depth integrated analyses can such an essential understanding of the aquatic populations be gained. As the benefits for fisheries management of such a comprehensive and searching analysis of substantial ocean areas are obvious, the ecosystem approach to assessment is now being advocated generally. There are, however, also many warning voices being raised that echo the recommendations made in the previous essay on the History of Fisheries Science.

This warning is that no matter how clear the picture of the resources becomes, unless these assessments are accompanied by sound governance, ecosystem assessment will be no more effective than the systems of the past in ensuring sustainable management of fisheries. The suggestion made previously that fisheries science should be paralleled by operations research is not only good, but also probably an essential underpinning for sound fisheries management.

EDITORIAL COMMENT

Microbial concerns

In the essay on biological oceanography the intricacies of the "microbial loop" have been touched upon in an examination of the elements of primary productivity. The microbial loop is the process whereby microbial mineralizers and their grazers reprocess and return to the food web, phytoplankton and other materials that had escaped initially; these amounts can equal approximately half of the primary production in the oceans. The importance of the microbial world in the overall biological oceanographic or biogeochemical world can be gauged by the fact that up to 97-98% of the living carbon in the seas is estimated to be composed of the bacterioplankton (bacteria and phytoplankton) and the zooplankton with the remaining 2-3% made up of macrobiota (invertebrates, vertebrates and macroalgae) (Table 1, Fig 2) (Kepkay 2000). Thus the major question of what are the relations between elemental cycling

Table 1 Standing stock of phytoplankton biomass in the world's ocean compared with primary production and decomposition of the primary production by respiration (from Kepkay 2000)

Primary (phytoplankton) production[a] (Gt C year-1)	Carbon turnover by respiration (days)	Standing stock of phytoplankton[b] (Gt C)
45	10[c]	1.2
50	80[d]	11.0

[a] Upper and lower limits of primary production from Longhurst et al. (1995)
[b] Calculated as the product of primary production and carbon turnover
[c] Lower limit of (fastest) carbon turnover from Eppley et al. (1977)
[d] Upper limit of (slowest) carbon turnover from Brenner (1998)

and food web structure is largely related to understanding the microbial activities within the oceans as these are key factors governing the dynamics of biological productivity directly comparable to the fundamental knowledge of soil microbiology and soil chemistry upon which so much of the success of modern agriculture and forestry depends. Gaining a clear picture of the microbial activities, however, constitutes a major challenge and requires considerable changes in perspective as the solution requires work in two areas of emerging importance: 1) the Archaebacteria and 2) the increasing recognition of the existence of and the major roles of biofilms.

A significant portion of the cycling of materials in the oceans is carried out by a group of microorganisms little studied in the past, the Archaebacteria. This group of prokaryotes lives in the most extreme of environments and includes hyperthermophiles, psychrophiles, methanogens, thermoacidophiles and halophiles (Grabowski & Kelman 2003) and in fact form a domain separate from the true bacteria to which they are only distantly related. Because their culture has proved so challenging, the study of the Archaebacteria will probably have to rely largely on important additions and extensions to the genomic approach mentioned earlier.

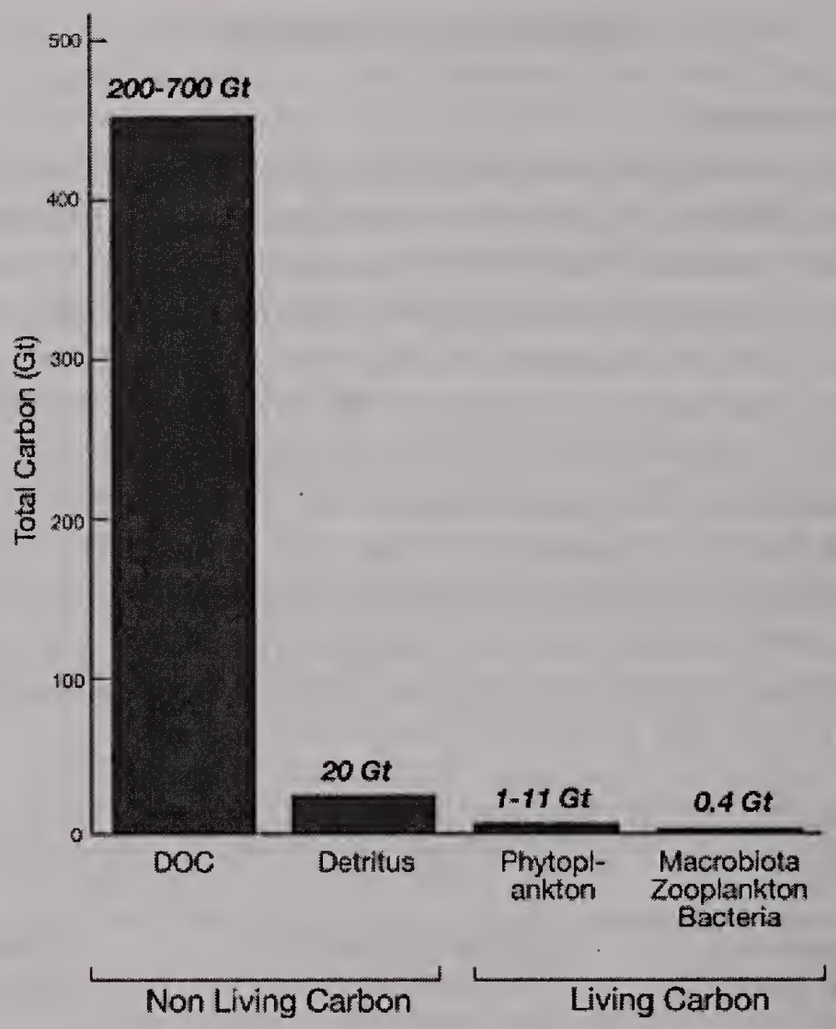

Fig 2 Oceanic living carbon vs. total carbon in gigatonnes (Gt) (redrawn from Fig 1, Kepkay 2000).

To the difficulties of dealing with the Archaebacteria will be added the problems of fathoming the activities carried out by bacteria in biofilms. It is now increasingly apparent that the bulk of the microorganisms in the water bodies do not exist or function in single planktonic forms, but actually coalesce and function in biofilms in manners quite different from the several to numerous individual species of which they are composed. Biofilms composed of both true bacteria and Archaebacteria can be thought of as multicellular organisms in which the individual members, with frequent changes in composition and basic capacities, develop new and interdependent specialities and form complex chemical signalling systems that coordinate and control responses throughout the biofilm (Shapiro 1998, O'Toole et al. 2000). Costerton et al. (1999) have defined the bacterial biofilm as a structural community of bacterial cells enclosed in a self produced matrix and adherent to an inert or living surface i.e. a protected and specialized mode of growth that allows survival in a hostile environment. An example of the complex techniques required to decipher the activities of biofilms is offered by Ram et al. (2005). They used genomic and mass spectrometry-based proteomics methods to evaluate gene expression, identify key activities and the partitioning of metabolic functions in a natural acid mine drainage biofilm community. They also found that the bacterial proteins involved in protein re-folding (stress proteins or molecular chaperones) in

oxidative stress were highly expressed, suggesting further opportunities to use these techniques in gauging pollution effects upon biofilms and, by extension, to the effects pollution has on the food webs.

Resource concerns

Although the Eastern Scotian Shelf analysis for the NAFO Division 4VW (Marine Ecosystems Assessment) is extremely impressive, it does not answer all questions nor does it immediately exhibit the means whereby this relatively large area could or should be managed sustainably. A good example of the complexity of these issues and the challenges to science and management is revealed by examination of the long-term picture of the landings for all of Atlantic Canada of the species now generally the most valuable, the lobster, *Homarus americanus* (Fig 3). The fishery has

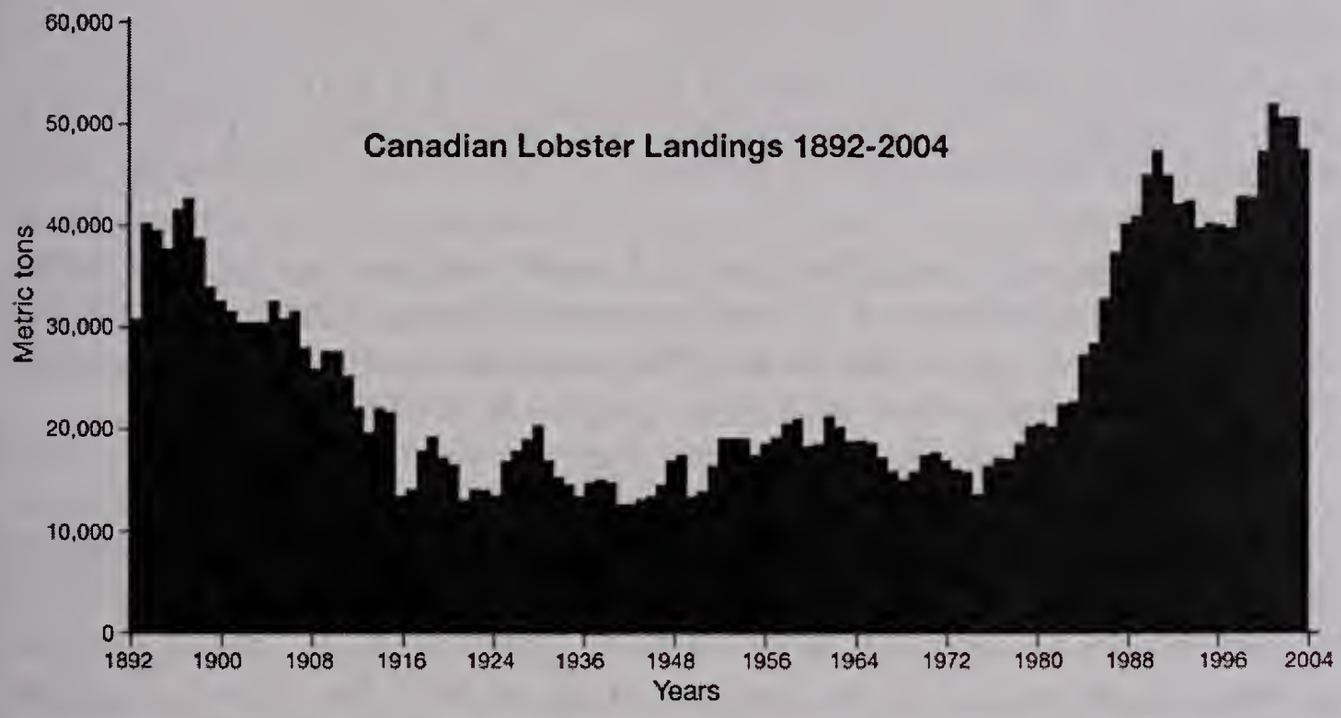

Fig 3 Canadian lobster landings 1892-2004 includes the landings in all of the areas now within the Canadian Atlantic Zone (courtesy of DS Pezzack).

existed in Atlantic Canada since the 1860s reaching a peak in the 1880s (McLeese & Wilder 1964) and has been managed largely by carapace size limits, protection of the females with externally attached eggs and by limitation of seasonal access. Largely through extensive and intensive laboratory-based studies on individual lobsters, the life history, needs, behaviour and susceptibilities of the species are well understood. Unfortunately, as lobsters are solitary animals they spend much of their time on the sea bottom hidden in crevices and shelters chosen to match the animal's particular life stage. Thus, despite much study, very little quantitative information is available regarding numbers of bottom dwelling lobsters until they reach the recruitment sizes and are landed in the fisheries. On a more positive note, the New England lobster settlement index survey, recently supplemented by limited Canadian involvement, has been examining the question of variability in larval settlement. The results have been interesting and it is

hoped that the settlement index will have predictive value for trends in the abundance of lobsters entering the fishery. As the authors state, however, the key question remains: what drives variability in lobster larval settlement in the first place (http://www.bigelow.org/srs/lobsterset.html)?

The pre-recruitment stage, in the warmer southern Gulf of St Lawrence areas is about 6 years while in the colder areas elsewhere it will run around 10 years. It is generally accepted that, in the areas fished, about 80% of the animals are captured in the year of their recruitment to the fisheries. Sexual maturity of female lobsters varies widely; in the Bay of Fundy and off southern Nova Scotia only 0-2% are mature at the minimum legal carapace size; off southern Newfoundland and in much of the southern Gulf of St Laurence 55-65% are able to reproduce at sizes below the legal size limit, while in the northern Gulf of St Laurence sexual maturity varies between 10 and 15% at the minimum legal carapace size (Pezzack 2006, see also Comeau 2003, Waddy & Aiken 2005). Thus, the rather slender apparent reproductive capacity of the various lobster stocks is always of major concern. In addition, as the larvae upon hatching are pelagic for periods up to 45 days prior to settlement and adoption of their subsequent benthic life, it is only rarely known with certainty where the brood stock for any particular area is located and thus the apparent health and success of the brood stock upon which the area fishery depends. Although there is qualitative information on who eats whom, very little area-wide quantitative knowledge of the lobster's interaction with other species is available.

An examination of Fig 3 illustrates that the yield from this fishery has varied widely over the 113 years illustrated. As with other new fisheries, the catch consisted originally of many larger animals drawn from a relatively numerous population. As the fishery proceeded the catch levelled out to consist mainly of animals freshly recruited (Herrick 1909). But, in contrast to many continuously fished species, in about 1980 the fishery suddenly ballooned with increasing annual landings eventually reaching levels in the 1989-2004 period higher than any recorded for the fisheries previously. As the landings consist mainly of animals that are 6-10 years old at the recruitment stage, whatever accounted for this sudden increase presumably must have begun in the 1970s or even earlier and would appear to have been maintained through to at least the late 1990s.

Although an upsurge in the landings of a valuable species is commercially rewarding, enormous unexplained swings in the numbers of any stock are, of course, extremely troubling for the scientists, managers and fishers. The negative side is the possibility that an unexpected and sudden decline could also occur and be just as surprising to all concerned as was the upsurge. While it is possible to examine these data using certain of the conclusions derived from the ecosystem analyses, any such analysis will suffer the shortcomings of any proxy analysis i.e., a distinct lack of certainty as to cause. Without sure knowledge of why the surge took place originally, it is not possible to predict whether it will last or for how long and thus it constitutes a major conundrum and challenge for science, management and

the fisheries. It also underscores the complexity of the issues that led Alan Longhurst to entitle his 2002 address to the International Council for the Exploration of the Sea "Fish stock management is an unsolved ecological problem".

CONCLUDING REMARKS

Unfortunately, although arranged to provide a sound basis for discussions concerning programs for the future, the coverage in this series of essays is not complete as it does not include such major areas as environmental science studies, aquaculture, chemical oceanography, in-depth treatment of biodiversity and most importantly discussion of more comprehensive treatment of invertebrates, macroalgae and benthic productivity generally. It is hoped that these areas can be covered in future essays as authors interested in preparing such treatises are found and/or persuaded to contribute them in the interests of programming, promotion of scientific literacy concerning the oceans and the intricacies and ramifications of ocean policies.

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MARINE GEOLOGY IN ATLANTIC CANADA - A GOVERNMENT PERSPECTIVE[1]

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The two priorities for government marine geoscience over the next decades are: (1) seabed mapping for ocean management, including safe and sustainable use of natural resources; and (2) societal responses in the coastal zone to natural hazards, global climate change and anthropogenic pressures including environmental degradation. Meeting these priorities will require scientific study of the history of past glaciations; erosion, transport and flocculation processes of sea-floor sediments, particularly of muds; and sediment transport and deposition and their interaction with environmental quality in estuarine systems, including the role of ice and storms. Numerical models are required to predict the consequences of natural rise in sea level and human interference in coastal systems and for predictive decision making in ocean management. Three recent revolutionary developments in technology will influence how science is done: these are the development of Global Positioning Systems (GPS), of multibeam sonar, and of digital data collection, storage and dissemination. However, other capital acquisitions and technological developments are necessary. These include new ships, expanded multibeam capability, and underwater autonomous vehicles. New photographic/video systems will provide resolution higher than that of multibeam bathymetry. In the coastal zone, remote sensing tools such as Light Detection And Ranging (LIDAR) and kinematic GPS will accelerate monitoring of coastal change. Cabled seabed observatories will provide time series and real-time information on extreme events. Research boreholes are essential to understand geological framework.

Les deux priorités du programme gouvernemental de géologie marine au cours des 20 prochaines années sont les suivantes : (1) cartographie des fonds marins pour la gestion des océans, et notamment l'utilisation sécuritaire et durable des ressources naturelles; et (2) les réponses sociétales, dans la zone côtière, aux risques naturels, aux changements climatiques planétaires et aux pressions anthropogéniques, notamment la dégradation de l'environnement. Pour réaliser ces priorités, il faudra procéder à des études scientifiques sur l'histoire des glaciations passées; l'érosion, le transport et la floculation des sédiments des fonds marins, en particulier des boues; le transport et le dépôt des sédiments ainsi que leurs relations avec la qualité environnementale dans les systèmes estuariens, notamment le rôle de la glace et des tempêtes. Des modèles numériques sont nécessaires pour prévoir les conséquences de l'élévation naturelle des niveaux marins et des interférences humaines dans les systèmes côtiers, de même que pour prendre des décisions prévisionnelles en gestion marine. Trois progrès révolutionnaires récents de la technologie vont avoir une influence sur les modes d'exécution des activités scientifiques : le développement du GPS, le développement du sonar multifaisceau ainsi que la collecte, le stockage et la diffusion des données numériques. Cependant, il faudra d'autres équipements et innovations technologiques,

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comme de nouveaux navires, d'autres dispositifs de sondage multifaisceau ainsi que des véhicules sous-marins autonomes. De nouveaux systèmes photographiques et vidéo offriront une résolution supérieure à celle de la bathymétrie multifaisceau. Dans la zone côtière, certains outils de télédétection (comme le LIDAR) et le GPS en mode cinématique vont accélérer l'observation des variations côtières. Des observatoires de fonds marins câblés fourniront des séries chronologiques et des données en temps réel sur les événements extrêmes. Des sondages de prospection seront essentiels à la compréhension du cadre géologique.

INTRODUCTION

Published scientific knowledge of the geological nature of the seafloor off Atlantic Canada first appeared in the second half of the 19th century, at first as a result of observations made by fishermen and from the laying of telegraph cables. Professor J.W. Bailey's studies of seafloor samples from east of Newfoundland in 1856 revealed volcanic ash, which he suggested might have been dropped from icebergs (Maury 1859). HMS *Challenger* visited Halifax as part of its investigation of the world ocean, dredging a granite boulder from south of Nova Scotia (Gossip 1873). US government investigations of the fishing banks (Verrill 1878) led to the recognition of the Grand Banks as an analogue of the Atlantic coastal plain of the eastern USA. Over the same time period, scientific studies of the coastal zone were the result either of the need to survey charts for safe navigation, or were an extension of studies of rocks on land. For example, Lyell (1849) studied the mudflats of the Bay of Fundy, applying his observations to the interpretation of ancient rocks. In his second edition of *Acadian Geology*, Dawson (1868) ascribed many of the coastal landscape features of Nova Scotia to the combination of sea-level changes and ice. Beach mining was an important source of aggregate at this time - "large quantities of ballast stone were sold annually" from McNabs Island in Halifax Harbour in 1849 and the same beaches supplied "a splendid brickworks" in 1855 (Manson 1999). The Saxby Gale of 1869, scientifically predicted by Stephen Saxby and Frederick Allison (http://www.magma.ca/~jdreid/saxby_gale.htm), resulted in widespread coastal damage in the Bay of Fundy and was probably the most devastating natural disaster in recorded history in New Brunswick (Ruffman 1999).

A century and a half later, we can still recognise 19th century themes in the issues and approaches to marine geoscience in Atlantic Canada. Economic pressures for marine geology research come from those exploiting the seafloor - the fishery and in the 21st century, the oil and gas industry. Seafloor communications are no longer by telegraph, but through fibre-optic cables, and the seafloor is also used for electricity transmission cables and gas pipelines. Understanding of the geological framework and geological processes is necessary for safe and sustainable management of seabed resources. In the coastal zone, although the ravages of beach mining have largely been halted, the sheer numbers of people wanting to live near and use the coast continues to increase. Causeways, bridges, docks, marinas and

shoreline protection structures impact the stability of the coastline. Coastal communities, and particularly the larger urban centres, have been subjected to nearly three centuries of waste disposal and marine environmental quality has suffered accordingly. As in Saxby's time, there is a need to predict the effects not only of storms, but also of the continuing rise of sea level, both exacerbated by global warming. Fundamental science provides the intellectual underpinning for effective human use of the sea floor and coastal zone, and as in the mid 18th century, scientific progress results from a mix of indigenous studies and international work on the world ocean.

This review considers the role of marine geoscience in government science in the coming decade in Atlantic Canada, from the perspective of the Geological Survey of Canada. Clearly, this government science will not be carried out in isolation, and important contributions will come from universities and the private sector, but both of these sectors respond to pressures that are different from those affecting government science. Regrettably, marine geoscience is highly dispersed in the Canadian university system, and does not achieve a critical mass in any single university. In Atlantic Canada universities have found it difficult to access Canadian ship-time and despite some successful collaborative projects with the government agencies, much of the Atlantic Canadian university effort in marine geoscience is carried on outside Atlantic Canada waters. Globally, research in industry has become focussed in fewer larger multinational companies and, consequently, industry in Atlantic Canada has limited Research and Development (R&D) capacity in marine geoscience and has traditionally looked to government agencies for that expertise. Recently, Petroleum Research Atlantic Canada (PRAC) (http://www.pr-ac.ca/), funded by oil companies developing reserves in Atlantic Canada, has identified a series of research priorities of interest to the petroleum industry and is providing support to universities and industry for such work. In contrast, the Atlantic Innovation Fund, established by the federal government in 2001 to encourage research to stimulate economic growth in the region, has only invested in marine geoscience indirectly through, for example, the petroleum-related Pan Atlantic Petroleum Systems Consortium.

SEAFLOOR MAPPING AND INTEGRATED OCEAN MANAGEMENT

In the next decade, the area of greatest change and advancement will likely be in seafloor mapping and its application to integrated ocean management. The advent of precise positioning through Global Positioning Systems (GPS) in parallel with the development of multibeam bathymetric tools has enabled rapid, high-resolution mapping of bathymetry and backscatter (a proxy for sediment type). In hydrocarbon basins, this is complemented by industry acquisition of 3-D seismic data that can be processed to provide high resolution bathymetry. These spatial data provide a context within which conventional point (sample, photography) and line (seismic, sidescan profile) data can be interpreted.

These new tools have revolutionized seafloor mapping. For the first time, they allow a view of the seafloor comparable with satellite imagery on land. They support many of the traditional applications of seafloor mapping: cable and pipeline routes, foundation conditions for seabed structures, the scale of bedforms that indicate sediment transport, intensity of iceberg scouring, offshore extension of bedrock structures, and the nature of the substrate for military applications (mines and sonar). They provide new insights into scientific issues such as the positions of former ice margins, ice-flow directions, drainage systems and former coastline positions and thus will make a major contribution to ice sheet and sea-level reconstruction and modeling.

Canada is a leading player in the emerging global awareness of such new tools and the development and application of the new map products to management of sustainable resources. In particular, habitat mapping is developing as a major new application of geoscience throughout the world as nations recognize the need to move from management of a wild fishery to ecosystem based management. Substrate is a primary control on benthic community structure (Kostylev et al. 2001). Precise maps of substrate allows bottom fishing effort to be managed in a manner more akin to agriculture than to hunting.

Canada, through the Department of Fisheries and Oceans (DFO), is a world leader in recognizing the need for an integrated approach to ocean management. The Canada Oceans Act of 1997 provides the legislative framework for development and implementation of a national strategy for ocean management, including the establishment of Marine Protected Areas (MPAs) and Large Ocean Management Areas (LOMA). The recently announced Oceans Strategy (http://www.cos-soc.gc.ca/) provides the vehicle to deliver on this legislation: seafloor mapping is at the core of the Oceans Strategy, acknowledging the power of the new tools and the need for a national program to systematically map the offshore lands. The need for ocean management arises from the multiple conflicting uses of the ocean floor - by various fisheries and aquaculture, by ecotourism, by hydrocarbon production platforms and pipelines, by telecommunication and electricity cables, and potentially for aggregate mining and in some inshore areas, for mining of placer minerals (Pickrill & Todd 2003). In addition, MPAs need to be set aside to preserve marine habitat and environmental diversity. Emergence of the concept of integrated ocean management, embodied within legislation and embracing the principles of a precautionary approach and sustainablity, provides a framework for decision making and establishing research priorities. Natural Resources Canada (NRCan), in partnership with the DFO, recognised the need to systematically map Canada's offshore lands to deliver the knowledge for ocean management and have completed extensive cross country consultations and feasibility studies to scope a national seafloor mapping program (SeaMap).

Canada has recently ratified the United Nations Convention on the Law of the Sea (UNCLOS) (http://www.dfait-maeci.gc.ca/department/focus/UN-

CLOS-en.asp). The Atlantic margin of Canada is exceptionally wide and is potentially open to an extended margin claim. Preliminary estimates (Macnab 1994) suggest Canada could gain as much as 1.76 x 106 km^2 new territory in offshore lands, i.e. equivalent to the area of the three prairie provinces. The bathymetric and sub-surface geological basis of such a claim unquestionably includes seaward extension of the continental shelf and slope beyond the current 200 mile territorial limit offshore both Nova Scotia and Newfoundland; the federal government has recently funded hydrographic and seismic surveys to support this case. Hydrocarbon exploration is already underway in lease blocks that extend beyond the current 200 nautical mile limit off Newfoundland. Territorial claims will be one of the emerging issues (along with hydrocarbons) that will continue to drive geoscience R&D beyond the edge of the continental shelf.

The petroleum industry is at present one of the principal users of government geoscience R&D. The cyclicity of the industry and the global nature of most of the large companies means that the wealth of corporate knowledge built up during the last phase of heightened exploration in the late 1970's and early 80's is no longer available to most of the companies. Consequently, companies active in the east coast offshore today lack a detailed knowledge of the regional geology of the seabed or of some of the unique conditions that occur. Sable Island Bank, the Grand Banks, and the Scotian Slope all have unique geohazards and foundation conditions that are quite different from those in the Gulf of Mexico or the North Sea. The offshore regulators Canada Newfoundland Offshore Petroleum Board (CNOPB), and Canada Nova Scotia Offshore Petroleum Board (CNSOPB) lack R&D capacity and look to government science programs to provide an independent evaluation of geohazards and environmental risk in offshore development. At present, issues on the continental shelf are concerned mainly with the stability of production facilities and the routing and stability of pipelines. Monitoring of the environment and sediment process studies are thus important in these areas. The new frontiers are in deep water, on the continental slope off Nova Scotia, parts of the Grand Banks, Flemish Pass and Orphan Basin, with the possibility that exploration will once again move to offshore Labrador and the Gulf of St Lawrence. Geohazards are poorly understood and spatially variable so that definition of the regional geological framework is the key activity in these areas.

Offshore aggregate has potential to become a valuable industrial mineral in Canada over the next 50 years. In areas such as western Europe, as much as 20% of aggregate resources are derived from the North Sea. Nova Scotia, in particular, has proven shallow water reserves and is well placed to supply markets in the northeastern USA. Feasibility studies are being considered for commercial development. The government science role will include both resource assessment and development of an acceptable code of environmental practice. Before a new industry can develop, a legislative and regulatory framework needs to be established for offshore mining. At present, the Department of Natural Resources Canada (NRCan) is obligated

to provide mineral resource assessments of all proposed MPAs to ensure future offshore resource development is not compromised.

THE COASTAL ZONE: BEACHES, ESTUARIES AND HARBOURS

The challenges in the coastal zone of Atlantic Canada are driven by two main factors. One is the natural rise in sea level (of a few mm per year in much of southern Atlantic Canada, but falling in parts of northern Newfoundland and elsewhere in northern Canada), in all probability accelerated by the impact of global climate change. The second is the maintenance of environmental quality in estuarine and other coastal systems under pressure from population increase in the coastal zone and increasing use of the marine environment by industry, aquaculture, and recreation.

Canada has the longest coastline of any nation in the world, yet generally a very low population density near the coast. The national strategy is thus to accommodate to natural and enhanced coastal retreat as sea level rises. Locations where key infrastructure is at risk will provide the exception to this strategy. Consequently, research needs to focus on vulnerable shores with the greater population densities and on predicting shoreline change on say 20, 50 and 150-year time frames. Until recently, high resolution studies of coastal change were laboriously time consuming. The advent of increasingly higher resolution remote sensing techniques, such as satellite imagery and LIDAR, are changing our ability to effectively study large areas of the coast. Research will necessitate continuing maintenance of coastal monitoring networks and a thorough understanding of nearshore processes and sediment budgets. Changing climate will focus research on impacts and adaption to both continuous change and extreme events.

Because of the societal consequences of coastal retreat, geoscience will increasingly need to be taken to the affected communities in an integrated manner, partnering with social scientists, engineers and planners (as done recently for the City of Charlottetown; McCulloch 2002). Communities need to be involved and empowered, which will require the preparation of information and tools that can be readily used by groups to address their own issues. Knowledge dissemination to communities is a far greater challenge than the geoscience information needs for offshore regions, where there are a small number of users who either have substantial technical competence or can be brought up to speed rapidly on a one-on-one basis. Initiatives such as Coastweb (http://agcwww.bio.ns.ca/COASTWEB/) and the establishment of the Climate Change Impacts and Adaptation Research Network (C CIARN) at the Bedford Institute of Oceanography (BIO) are attempts to provide effective communication. They form part of a general trend in government to make all “knowledge” available on line, with user-friendly digital products.

Many coastal communities are founded in marine based economies. Following collapse of the ground fishery, the challenge has been to establish a broader sustainable economic base in our estuaries and harbours and

coastal waters. Exploiting new opportunities, such as aquaculture and ecotourism, and balancing these with historical and culturally engrained practices will present a new set of challenges requiring basic research into the understanding of estuarine circulation and sedimentation and the impacts of anthropogenic activity such as waste disposal, dredging and fish farming on coastal systems. Research will be cross disciplinary, have a process focus, and necessitate close partnerships between geoscientists, biologists and oceanographers. Sustainable economic development in rural and coastal communities must address issues of integrated coastal zone management and marine environmental quality.

THE GEOLOGICAL FRAMEWORK

Understanding the geological framework of Atlantic Canada is essential for effective management of the seabed and the coastal zone. Several key issues are identified. The rheology and state of stress in the Earth's crust and its resulting deformation are a consequence of regional plate tectonics and past and present loading, particularly the effects of ice loading 20 to 10 thousand years ago (Peltier 2002) and the effects of sediment loading (Courtney & Piper 1992). The effects of past ice-loading are largely responsible for the present rates of relative sea level rise of several mm a year in much of Atlantic Canada (Shaw et al. 2002) and improved understanding of past ice-loading will enhance future prediction of future sea level rise (www.dal.ca/~cnef/NewFiles/Acid-wkshp-proc'02.doc).

The history of past glaciations is important not only for understanding crustal deformation. The morphology of the continental shelf is largely a consequence of glacial erosion. The upper tens to hundreds of metres of sediment beneath the seafloor on the outer continental shelf and deep continental margin were deposited either directly from glacial ice that extended to the shelf edge only 20 thousand years ago, or from glacial meltwater laden with sediment eroded from Atlantic Canada. Glaciation provides a paradigm for understanding and thus predicting seabed conditions in Atlantic Canada (Syvitski 1993). Improvements in our understanding of glacier dynamics, new data from critical offshore areas, and the chronological revolution provided by Accelerated Mass Spectrometry (AMS) radiocarbon dating mean that a new synthesis of the glacial history of Atlantic Canada including the marine realm is both necessary and timely.

The transport of sand on banks of the continental shelf is reasonably well understood as a result of studies in the last two decades and a predictive modelling capability has been developed (Amos & Judge 1991) including the evolution of "community models" (http://woodshole.er.usgs.gov/project-pages/sediment-transport/). However application has been limited to a few demonstration projects related to engineering infrastructure, such as the Sable offshore gas field. Broader application is required to understand regional sediment dynamics and bank stability on the shallow Scotian Shelf and in the deeper water of the upper continental slope, to support planning

for offshore development and habitat management. Fine grained marine sediments are the ultimate depocentres for many terrestrial pollutants. The understanding of transport, sedimentation and erosion of fine grained sediments, particularly in the coastal zone, is minimal.

Over the past two decades, the description of beaches and large-scale processes of cliff retreat and barrier-beach failure have been synthesised in robust conceptual models of the response of beach systems to rising sea level, storms, and beach mining. Many of the processes, however, are stochastic, and with the great developments in numerical modelling in the past decade, there is now a need for much more effective numerical models to evaluate the consequences both of natural rise in sea level and human interference (such as the re-opening of old causeways) on beaches and the estuarine systems behind them.

Estuaries and harbours were the earliest focus of marine geology at BIO, with work on Chedabucto Bay, Baie des Chaleurs, the Bay of Fundy, and Halifax Harbour, but have been largely neglected in Atlantic Canada since the 1970's. In more densely populated areas of the world, embayments such as Chesapeake Bay, Long Island Sound, and the Strait of Georgia continue to be intensively investigated. Such studies are directed at understanding sediment transport and deposition and their interaction with environmental quality, as a result of population pressures including sewage discharge, dredging and ocean dumping. Atlantic Canada shares many of these issues but also has unique scientific problems in coastal embayments. Tidal range and sediment transport in the Bay of Fundy are extreme, resulting in rapid siltation seaward of structures such as coastal causeways. The presence of winter sea-ice over much of Atlantic Canada is a complication absent in most densely inhabited estuarine regions. The "shallow fiord" coastline of much of the Atlantic coast of Atlantic Canada (Stanley 1968) results in sediment dispersion and distribution quite different from that of either low-lying coastal estuaries or of deep fiords (Piper et al. 1983). Many of the fundamental processes of sediment transport and deposition remain poorly understood.

THE NEW SCIENTIFIC TOOLS

Much of the equipment utilised by marine geologists in offshore surveys has changed little over the last 20 years. The basic mapping tools of high resolution seismics and sidescan sonar have witnessed incremental improvements (e.g. chirp seismics), but the coarse glacially derived sediments of the Atlantic margin still present a challenge to high resolution seismic reflection profiling. Bottom camera systems have improved, digital videography has replaced film, and bottom sampling has seen the development of video grabs and improved corers, but again improvements have been incremental rather than revolutionary. The three most significant advances that have and will continue to change our research procedures and advance our scientific understanding are:

1) The development of GPS, providing routine accurate positioning and repeatability
2) The development of multibeam sonar, providing the first accurate high-resolution imagery of the seabed and of automated processing routines for multibeam and backscatter.
3) The transition to digital data collection, and the associated computer capability to manipulate large data sets, process them and distribute products through the World Wide Web.

Marine geoscience survey practice has been transformed from a single ship operation to a two step survey, i.e., a regional multibeam mapping program followed up by targeted "ground truth" surveys utilising traditional tools but much less ship time. Canada, through a partnership with the Canadian Hydrographic Service (CHS), the Geological Survey of Canada (GSC) and the University of New Brunswick, has been at the forefront in adopting multibeam technology and applying it to geoscience. Canada has state-of-the-art equipment and major regional surveys are being conducted, but additional capacity is required to enable these new survey practices to become routine. Nevertheless, multibeam sounding has probably provided a greater leap forward in our understanding of marine geology in Atlantic Canada than in most other parts of the world. The wide, shallow continental shelf, glacial and transgressive history, and energetic seabed have left bedrock, moraines and till exposed at the surface to be modified by hydrodynamic processes. The seascapes emerging from multibeam surveys are spectacular, always providing unexpected insights into our understanding (Fig 1).

For the most part, government marine geoscience research is conducted from the government research fleet, operated and managed by DFO. This research fleet is old – the CCGS *Hudson*, commissioned in 1962, is the only blue water research vessel available for the Atlantic margin. The fleet requires modernisation with cost effective ships for shelf and open ocean deep-water work. Multibeam capability was originally provided for hydrographic needs, but as utilisation has extended to other mandates this capacity has proven to be inadequate, and new systems are required from coastal to deep water environments. It is likely that autonomous underwater vehicles (AUVs) will become the platform of choice for multibeam in the next decade.

The oil industry has driven the improvement in seismic reflection techniques to better define hydrocarbon reservoirs. Globally, 3D seismic reflection has provided the revolution in subsurface imaging that the multibeam instrumentation has delivered at the seabed. Unfortunately, 3D seismic surveys are extremely expensive and remain the domain of a few large multinational survey companies delivering data to client lease-block holders. Nevertheless, the high resolution, near surface data is proving invaluable to the government research program and the GSC Atlantic has been proactive in partnering with industry to access these data. This trend must be continued

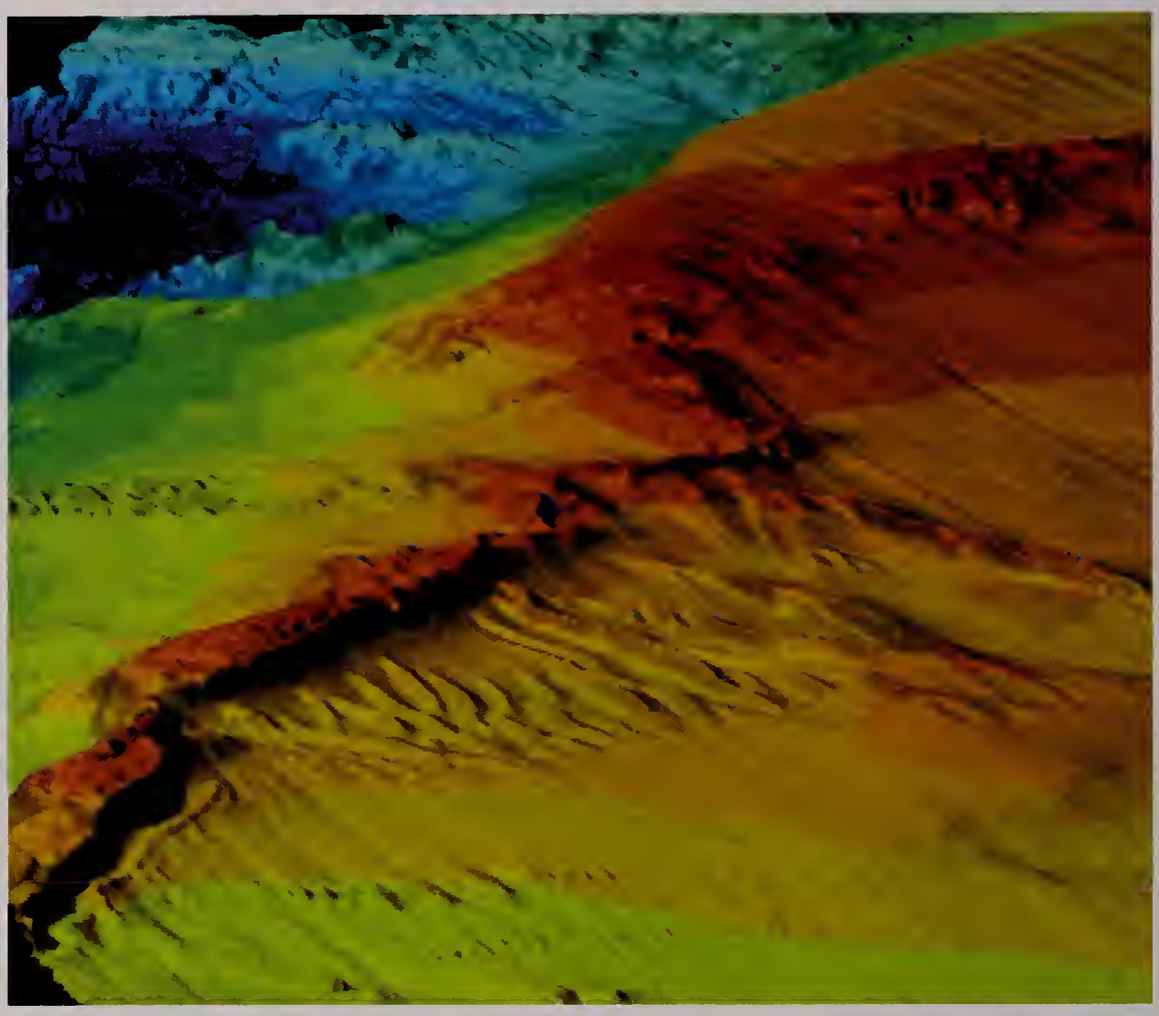

Fig 1 Oblique view of the Fundian Moraine, Browns Bank, Scotian Shelf. Field of view approximately 8 km. Water depth on top of ridge is 30 m. Multibeam mapping reveals that the Fundian Moraine is a complex feature composed of interconnected, lobate morainal segments, breached in places by low-relief sea floor. The flat top of the moraine suggests that it was subjected to erosion during sea level rise (Todd et al. 1999).

and placed on a more formal foundation in the future. In addition, there is a need for improved high-resolution seismic data, which will require systems with a deep-towed receiver and potentially a deep-towed source. AUV's may develop as the platform for such data acquisition.

As our ability has improved to image the seafloor accurately and with precise positioning, the "groundtruthing" of this imagery has moved away from textural analyses of discrete bottom samples toward characterisation by bottom photography and videography. Seafloor targets can now be revisited with pin-point accuracy. Technological developments with low-light imaging systems and digital storage and manipulation of images means that there are new opportunities for direct seabed imaging ("photography" or "video"). Multibeam bathymetry provides horizontal resolution on a scale of metres: for many issues related to sediment transport and benthic habitat, resolution on a scale of centimetres is required. Digital imagery, combined with distribution of map products and data bases through the web and on computer disc enables photographs and video clips to be incorporated directly into these new products. Despite shared camera and

video equipment between DFO and NRCan, the focus on shelf research over the last 20 years has been at the expense of the deep water studies. Research on slope geohazards, The Gully, and deep-water corals has been constrained by an inability to collect quality imagery beyond water depths of a few hundred metres.

No direct samples of sediments and rocks more than a few metres below the sea floor are available off eastern Canada, except for cuttings and sparse cores in areas of petroleum exploration (these make up only a small proportion of the Canadian offshore territory). Only one Deep Sea Drilling Project/Ocean Drilling Program sites is located within the 200-mile limit off eastern Canada (Site 645 on the Baffin Slope), with one other (Site 111 at Orphan Knoll) potentially within Canadian territory under UNCLOS and Site 384 on the J-Anomaly Ridge not far beyond the limit. This contrasts with tens of sites off the USA, France, the UK, Brazil, Japan, New Zealand and Australia. The geological framework of the Canadian marine territory is thus largely interpreted from remote-sensing geophysical data, except in well-drilled hydrocarbon basins. Sea-floor drilling is needed to provide basic knowledge of rock distribution beneath the continental margins, reference stratigraphic sections for hydrocarbon basins (analogous to the US COST program of the late 1970s), information on paleoclimate and past glaciation adjacent to Canada, and an understanding of the risk of catastrophic, deep-seated slope failure. The cost of such drilling will require a consortium approach, and include industry, government and academia, and probably also international partners.

Canada, with the longest coastline in the world, has always been a centre for research in remote sensing and application of these techniques to geoscience. High resolution photogrammetry has been the foundation for both coastal mapping and long term monitoring of major shifts in coastline position. Coastal surveys have always been labour intensive and reliant on sparse profile data. Kinematic GPS, and the increasingly higher resolution and broader applications of satellite remote sensing are beginning to transform coastal research, providing the opportunity to deliver greater geographical coverage, higher resolution and affordable repeatability.

In oceanography, a trend internationally has been toward establishing seabed observatories, or long term monitoring opportunities. The benefits to operational oceanography are obvious, but are equally significant in advancing our understanding of seafloor processes. Canada has acknowledged these directions with the recent announcement (by the Canadian Foundation for Innovation (CFI) and the BC Innovation Fund) to fund the US/Canadian “Neptune” and “Venus” projects on the Pacific margin, and Natural Sciences and Engineering Research Council (NSERC) and CFI sponsored observatories on Vancouver Island, the South Shore of Nova Scotia and on the west coast of Newfoundland. Such observatories provide long term time series of the state of the seabed and real-time observations of extreme events. To date, such observatories have been driven by the university sector, but they also provide great opportunities for government

laboratories to get involved. They also have direct relevance to many industry issues (the state of stress and pore pressures in slope areas with historic landslides; the transport of seabed sediment). Offshore production platforms may provide an opportunity for short cabled links to specialised seabed observatories.

Globally, geoscience research is in the midst of a digital revolution. As an example, at the GSC Atlantic, digital data bases have largely been populated over the last six years and have matured to the state of being operational and on line. Canada's national marine geoscience repository contains information from over 1100 cruises, and more than 18000 cores. The next phase in this evolution to a digital world is to produce value added products and "knowledge" disseminated on line to all Canadians. "BASIN", the GSC Atlantic hydrocarbon data base, currently provides this functionality. Digital atlases, containing raw data, photographs, mosaics, seismic lines and interpretive map products and text, are now becoming standard. The digital medium provides flexibility to tailor products to specific requirements, yet at the same time delivering within evolving national and international standards. Integrated management of Canada's oceans in the 21st century calls for the seamless integration of data and knowledge from all government agencies contributing to ocean management. This is one of the objectives of the Marine Geospatial Data Infrastructure Program of Geoconnections. At a local level DFO (Science, Oceans and CHS) and NRCan are co-funding research to integrate data within the East Scotian Shelf Integrated Management Plan (ESSIM). The architecture is largely in place to make digital geoscience information readily available to the public. Effort is now required to complete populating the data bases, apply adequate quality control over this data, generate new interpretive map products, and integrate the geosience data with other marine data bases.

LESSONS FROM THE INTERNATIONAL COMMUNITY

At first sight, the major emphases of the international community in marine geology are rather dissimilar from the pressures in Atlantic Canada. That was perhaps the same as in the mid 18th century, when recognition of the "Telegraphic Plateau" and the prescient observation that "it extends around the Earth as a Ridge" (Maury 1859) only became of direct relevance to Atlantic Canada with the development of plate tectonics more than a century later.

Prediction of the magnitude and effects of future climate change is the major societal issue currently being addressed by the international scientific community. Although in Canada, emphasis is on mitigation and adaptation to the impacts of climate change, many international studies are using the paleoceanographic record to understand the style and linkages involved in past rapid changes in climate. These involve (1) decadal variability in the Holocene, for which there is a record in eastern Canadian fiords and

which may be related to changes in the Earth's magnetosphere (St.-Onge et al. 2003); (2) changes into and out of past interglacials; and (3) studies of major warm events in distant geological time, such as the Paleogene Thermal Maximum. The fact that the middle of the 21st century will see an insolation minimum underlines the importance of understanding complex climatic linkages, given the lack of significant predicted warming in Newfoundland and Labrador.

The integrated understanding of sediment transport in the world ocean (from source to sink) is the marine geology focus of the US Margins program (http://www.soest.hawaii.edu/margins/SedStrat.html) and is a successor to the STRATAFORM project and is complemented by EUROSTRATAFORM. Studies of this type have been concerned with processes in large scale river-fed sedimentation systems and the resulting deposit architecture and are of direct relevance to past sedimentation on the continental margin off Atlantic Canada and the evolution of petroleum basins. New insights into marine sediment transport processes arising from such studies should be directly applicable to Atlantic Canada.

The Integrated Ocean Drilling Program (IODP) (http://www.iodp.org/isp.html) initiated in 2003, has identified three key science issues that can be solved by drilling in the oceans: the deep biosphere in the sub-seafloor ocean; environmental change (in the ocean), processes and effects; and solid Earth cycles and geodynamics. Such long-term science is likely to be addressed more by universities than by government scientists in Canada. Unfortunately, Canada has not yet found a way to fund on-going membership of IODP.

Other international science issues have more direct resonance with issues in Atlantic Canada. The stability of continental slopes is a major issue world wide (http://otrc.tamu.edu/Pages/B119.htm), both because of its significance to seafloor hydrocarbon production facilities and trans-Atlantic cables and because of the far-field risk of tsunamis generated by slides on continental slopes (such as the 1929 Grand Banks event, which killed 28 people in southern Newfoundland) or on volcanic islands (Ward & Day 2001). The application of geological habitat mapping to better management of the diminishing world fisheries resource, work pioneered by industry and government in Atlantic Canada (Kostylev et al. 2001), is now receiving worldwide attention. For example, the European Union recently announced major funding for "HERMES" (Hotspot Ecosystem Research in the Margins of European Seas) (http://www.eu-hermes.net/), an international multidisciplinary program designed to provide new insights into the biodiversity, structure, function and dynamics of ecosystems and their natural environment along Europe's deep ocean margin. Environmental quality studies in inland seas such as the Baltic and Mediterranean seas as well as the coastal zone are providing methodology and concepts applicable to areas such as the Gulf of St. Lawrence and the St. Lawrence Estuary. Major instrumented studies of beach systems (e.g. at Duck, North Carolina (Birkemeier et al. 1985) and in the Netherlands (Ruessink et al. 2000)) will provide new understanding of

beach dynamics and hopefully lead to stronger predictive ability in coastal engineering of beach systems.

The international marine geoscience research community is small and shares common problems in conducting research in severe environments. The community in Canada benefits from strong international links, to both colleagues and institutions, enabling timely gathering of intelligence, and timely adoption of new techniques, resulting in cost effective state-of-the-art research being conducted in Atlantic Canada.

WHAT WILL BE THE CONTRIBUTIONS OF GOVERNMENT MARINE SCIENCE TO MARINE GEOLOGY OVER THE NEXT DECADE?

One of the unquestionable strengths of marine science in Canada was the visionary decision in the 1960's to create multi-disciplinary research institutes first as the Bedford Institute of Oceanography (BIO) at Dartmouth and later the Institute of Ocean Sciences (IOS) at Sidney BC. The benefits of co-location of scientists, sharing equipment, platforms and workshops, has created a critical mass which established Canada as a world leader in oceanographic research. Financial cutbacks have strained working relationships, but the need today for interdepartmental collaboration is greater than ever. Much of the basic understanding of the marine science of Atlantic Canada has been gleaned from single discipline studies. However, many of the challenges in the future require a more holistic understanding of marine ecosystems that necessitate research in multi-disciplinary teams. For this to succeed a paradigm shift is required to move away from establishing research priorities within the silos of individual departmental mandates to recognising national and federal priorities in marine science and developing cross departmental funding mechanisms to deliver the required programs.

The requirements to deliver knowledge to implement Integrated Ocean Management has led several countries to develop programs to systematically map offshore territories. Ireland is midway through a survey program, the Norwegians have recently funded the "Mareanos" program to map their central coast, the Australian government has established a National Oceans Office, which among other tasks will establish mapping priorities. In Canada, successful collaborative pilot mapping projects between DFO and NRCan led to funding for cross-country consultations to develop a national strategy, "SeaMap", to map Canada's offshore lands. This strategy will form the basis of ongoing mapping programs in Atlantic Canada. Geoscience surveys and habitat modelling have been central to establishment of MPAs such as The Gully, and to the development of management plans for LOMA, such as on the Eastern Scotian Shelf (ESSIM). These pilots are precursors of the application of mapping to underpin Canada-wide management strategies in the future.

The last 15 years has witnessed major changes both in Canada and globally in the approach of governments to geoscience and oceanographic research. While each country has responded differently, the cycle in the

western world has been common: cut-backs in support of federal programs in response to economic difficulties, divestiture of programs that might be considered completed or no longer relevant, and redefining programs to be closer aligned with government short-term priorities. The most successful laboratories (e.g., Southampton Oceanography Centre – UK, NIWA – New Zealand) have been those with the flexibility to respond to emerging priorities and a demonstrated relevance to national needs. Within this context, one of the greatest challenges is to balance delivery of immediate short term objectives with longer term strategic research needs, at the same time maintaining a balanced national program. The GSC has responded well to these challenges: following a 35% cut in resources through the mid 1990's, new opportunities for applying marine geoscience have been grasped. For example, international leadership has been applied to geoscience for habitat mapping and integrated ocean management; creative partnerships with industry enabled acceleration of research on the emerging frontier of the Scotian Slope to meet regulator and industry needs; an interdepartmental team, involving all levels of government, evaluated impacts of sea level rise and developed adaptive strategies for coastal Prince Edward Island; and the GSC played a leadership role in Canadian participation in the Ocean Drilling Program. Relevance to the Canadian public continues to be cemented through partnership and delivery of successful programs.

The GSC has realigned and redefined research programs across Canada. Within this framework, marine geology is strongly aligned with objectives of the "Geoscience for Ocean Management"(GOM) (http://www.gom.nrcan.gc.ca) and "Climate Change" Programs. With central themes of geohazards, integrated ocean management, marine environmental quality, habitat mapping and sea level rise impacts these national programs are clearly aligned with the research needs of Atlantic Canada and will provide the cornerstone for future research directions.

WHAT ARE THE CONSTRAINTS TO MAKING THESE CONTRIBUTIONS?

A number of structural social and political factors make the task of meeting these future scientific challenges more difficult. There is no effective national science policy on the oceans, within which government and university research priorities can be established. In the last decade, the government has moved away from funding core programs to supporting targeted initiatives, cross-cutting research and industry sectors. While this approach may diminish the fragmentation of the university sector in marine geoscience, it exacerbates the problems of developing a national geoscience research strategy. The GOM Program is NRCan's response to align research with government priorities. The Canada Oceans Action Plan (COAP) announced in the 2004 Speech from the Throne, represents a concerted effort to consolidate government ocean activities and provide

focus for ocean management and research, cutting across departmental and sectoral silos. The shift in resources from government laboratories to universities in the 1990's, without any significant shift in responsibilities, has made recruitment of talented staff more difficult.

The age structure for professionals in government science organisations (and to a lesser extent in universities) is highly skewed towards the older age brackets. Recruitment of government scientists to replace those retiring will thus be in direct competition with not only Canadian universities, but also industry and international employers who are increasingly looking for geoscientists with marine experience. Strong strategic vision and increased resource levels will be necessary to make government laboratories the "workplace of choice" and to maintain their traditionally high scientific standards.

The age structure of infrastructure for marine geoscience parallels that of the scientists. It appears likely that the CCGS *Hudson*, the only blue-water research ship for Canada's Atlantic territory will still be in operation at age 50. Other vessels in the DFO fleet have been laid up over the last decade, creating pressure across marine sciences for available ship time. There is no low cost continental shelf research vessel on the Atlantic coast and no research vessel capable of handling the Canadian deep water Remote Operated Vehicle (ROV), "ROPOS". Historically major advances in marine geoscience research in Atlantic Canada have been driven through investment in technology, both in the laboratory and at sea. Many of these tools are aging, reinvestment in equipment is inadequate as national capital expenditures for science have been diverted through the CFI to the university sector. Attempts to pool marine geoscience equipment have failed (http://www.geoscience.ca/papersandreports/marinegeo.html): a new model for university - government laboratory cooperation is needed.

Industry is perhaps the most demanding of the clients for government science. Industry has greater flexibility and an ability to shift resources that is not matched in government, which therefore finds it hard to keep up with industry demands. New models of cooperation are needed with both industry and other government departments. The government will probably never be in a position to acquire new data such as 3D seismics and bore holes. As the oil industry moves from exploration to production the government needs to position itself to partner with companies, bringing regional expertise and complementary data to the table. The exploration industry is cyclic; during periods of downturn such as the 1980's, staff was released and many companies lost valuable expertise and most importantly valuable data. With the resurgence in offshore activity in the late 1990's, most of the major oil companies had no in-house capability and relied heavily on the GSC expertise and data as they rebuilt capacity.

Future advances in marine science will become increasingly cross disciplinary as traditional boundaries between disciplines are breaking down. Marine geoscience is recognised as one of the cornerstones of habitat mapping and ecosystem based management. The concept of geoscience playing a

significant role in management of living as well as non-living resources is a novel one for NRCan, but has been acknowledged and resourced as a government priority under the new GOM research program. However despite this progress, government science is delivered within individual departmental mandates and the opportunities and funding mechanisms to develop truly joint interdepartmental programs requiring resources from several departments are rare. Changes in the federal perspective on oceans research are required at senior levels within government departments to develop priority research areas for Canadian's that cross departmental mandates; this needs to be matched with an appropriate funding mechanism.

CONCLUSIONS - THE CRITICAL ISSUES

The editor of this series asked that we identify the major scientific problems of the coming decade and describe the impacts of solving these problems, but also the consequences of not solving them. The two priorities for government marine geoscience over the next decades are: (1) seabed mapping for ocean management including safe and sustainable use of natural resources; and (2) societal responses in the coastal zone to natural hazards, global climate change and anthropogenic pressures. The general field of environmental quality and sensitivity is likely to become increasingly important, as public awareness of environmental degradation continues to develop, in part through the proactive stance of Non-Governmental Organizations (NGOs).

To deliver these programs will require a strong Canadian science program (involving universities, industry and government) in the history of glaciation, sediment transport processes, numeric modelling (particularly of coastal zone changes), and estuarine studies and an increasingly multidisciplinary approach. New field tools will be needed, notably research vessels, an AUV, improved high-resolution seismic equipment and seafloor camera systems, and research boreholes. Improved methods will be required to deal with large volumes of data (particularly multibeam bathymetry and backscatter) and to deliver research "knowledge" to users. Canadian scientists will need to maintain and strengthen links with the international marine geoscience community in order to fill numerous gaps in the Canadian marine geoscience program.

The major population centres of Nova Scotia, Newfoundland and PEI are all located in the coastal zone, which is of great economic importance to the region and susceptible to natural sea-level rise. The economic costs of mitigating the impacts of global warming and environmental degradation can be minimised by a clear understanding of the scientific issues (as, for example, the Dutch investment in hydraulics research supported the widespread land reclamation in that country). The complexity of the modern way of life and the pressure that population places on our natural environment requires that decision- making be firmly founded in scientific understanding.

Marine areas adjacent to eastern Canada make up 30% of the Canadian territory. The 20th century is littered with examples of unconstrained development and inadequate planning leading to poor decisions and adverse environmental impacts on ocean systems. The 20th century witnessed an unprecedented depletion of marine ecosystem diversity and quality. Economic and environmental consequences have often been severe, such as the collapse of the ground fishery in Atlantic Canada. Recognition of the emerging role of high resolution marine geoscience in ocean management provides a fundamental new rationale for the GSC to support sustainable management of the living as well as the non-living resource. Within the global paradigm shift toward integrated ocean management marine geoscience has a responsibility to not just contribute to, but also lead integrated research underpinning the delivery of sustainable and precautionary management of our oceans.

Disclaimer and acknowledgments. The opinions of the authors are personal and do not necessarily correspond to those of Natural Resources Canada. We acknowledge the intellectual environment of the GSC and the Bedford Institute of Oceanography which encourages scientific questioning. We thank the two referees, Jeremy Hall and Phil Hill, for providing constructive critiques.

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PHYSICAL OCEANOGRAPHY IN ATLANTIC CANADA

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Physical oceanography has been practiced in Atlantic Canada since the beginnings of the science in the second half of the 19th century. Pursued largely as an applied science, its efforts have been directed toward providing information to mariners and other marine users. Early efforts focused on tidal observations to promote safe navigation. This was expanded in the early 20th century to regional studies in support of fisheries. In the second half of the 20th century, physical oceanography in Atlantic Canada grew to support the offshore development of oil and gas, provide more comprehensive environmental assessments of marine projects and processes, improve Search and Rescue responses and to better understand and predict climate change and variability. Oceanographers now have the capabilities to observe the ocean in near real-time using satellites as well as autonomous *in situ* instruments. The continued growth in computer power and other information technologies has permitted the development of operational ocean models that can provide real-time information and projections on oceanic conditions to a broad section of the marine community.

L'océanographie physique est pratiquée au Canada atlantique depuis les débuts de cette science au cours de la deuxième moitié du XIXe siècle. Les travaux dans ce domaine, menés dans une grande mesure sous forme appliquée, sont axés principalement sur la fourniture de renseignements aux gens de mer et aux autres utilisateurs du milieu marin. Les premiers travaux ont porté sur les observations des marées afin d'assurer la sécurité en mer. Au début du XXe siècle, des études régionales ont été lancées pour appuyer les activités de pêche. Au cours de la deuxième moitié du XXe siècle, l'océanographie physique au Canada atlantique a continué de croître pour maintenant appuyer les projets de mise en valeur du pétrole et du gaz en milieu extracôtier, fournir des évaluations environnementales plus détaillées des projets en milieu marin et des processus liés à ce milieu, améliorer l'intervention dans le cadre d'opérations de recherche et de sauvetage, approfondir les connaissances sur le changement climatique et la variabilité et améliorer les prévisions relatives à ceux-ci. Les océanographes ont maintenant la capacité d'observer l'océan presque en temps réel grâce à des satellites et à des instruments autonomes *in situ*. L'amélioration continue de la puissance des ordinateurs et d'autres technologies de l'information a rendu possible l'élaboration de modèles océaniques opérationnels qui peuvent fournir des données et prévisions en temps réel sur les conditions océaniques à une part importante de la communauté maritime.

INTRODUCTION

Physical oceanography describes, analyzes, models and predicts the physical marine environment and is focused primarily on ocean waves, tides, currents as well as ocean temperatures and salinities. Early oceanography

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was concerned principally with observation and description, but with the advance of scientific understanding and computing capacity, modeling and prediction has become a significant activity. It is a young science that arose in the nineteenth century, its development driven both by intellectual curiosity and by the needs of commerce and the military for better information on ocean winds, currents and tides.

Mariners have always observed the ocean and obtained a great deal of practical local information on ocean currents and tides as well as the location and behaviour of its living resources. From ancient times, this knowledge was preserved in stories, songs and poems, e.g. the Norse sagas. Systematic ocean observations began with Prince Henry the Navigator of Portugal, who directed the collection and codification of ocean observations, creating knowledge that supported the expansion of the Portuguese empire to Africa, Brazil and into the Indian Ocean. During the nineteenth century, both the US and British navies began the systematic collection of wind, current, pressure and temperature observations from the logs of commercial and naval vessels throughout the world. The international collection and exchange of these data were arranged at international conferences in 1853 and 1873. These data were synthesized into monthly pilot charts that allowed navigators to plan voyages on the basis of expected wind and surface current patterns. As these charts revealed the patterns of winds and currents, they became the basis of theories of global atmospheric and oceanic circulation.

The HMS *Challenger* expedition, 1872-1876, is usually considered to mark the birth of oceanography as a science. Halifax was this vessel's first port of call after it had occupied a series of oceanographic stations across the North Atlantic from England. The *Challenger*, on its departure from Halifax, occupied 8 oceanographic stations from the outer edge of the Scotian Shelf to Bermuda in May 1873 (Fig 1), perhaps the first oceanographic section across the Gulf Stream south of Nova Scotia. Much of the organization of the *Challenger* expedition was carried on by Sir John Murray, a Scottish-trained naturalist born in 1841 in Coburg, Ontario, for whom one of the buildings at the Bedford Institute of Oceanography is named.

Oceanography in Atlantic Canada began with the establishment of a tide gauge network in 1893-1895. In addition, W.B. Dawson carried out a series of tide and current surveys in 1894, 1895 and 1896 using the lighthouse supply steamer, *Landsdowne* and in 1903 the steamer, *Gulnare*. These surveys provided the observational basis for the prediction of the timing and strength of tidal currents in many of the key straits and passages of Atlantic Canada and established a better information base for marine transportation in the area.

Early global expeditions such as the *Challenger* expedition yielded a broad description of the physical, chemical and biological distributions in the oceans, but were not able to delineate the physical processes that governed those distributions. At the beginning of the 20th century, Nordic oceanographers and meteorologists were developing the theoretical basis

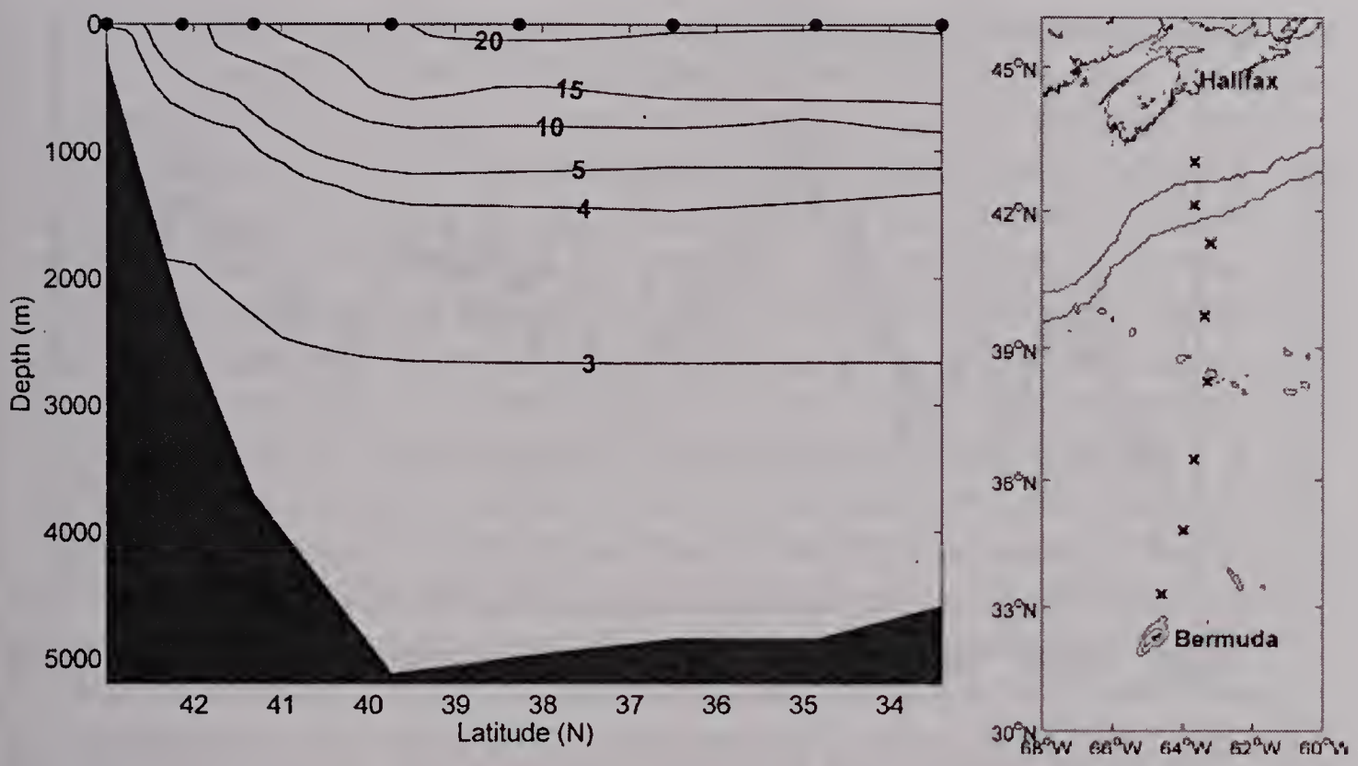

Fig 1 HMS Challenger temperature sections from the outer Scotian Shelf to Bermuda, May 1873. Sampling positions are indicated by a dot at 0m in the section and as an x on the map. The average station spacing of ~160 km is too coarse to resolve the Gulf Stream well, but the upward tilting temperature contours place the Stream near the base of the continental slope.

of the dynamics of the oceans and atmosphere and thereby pioneered the design of well-planned, systematic surveys of regional oceanographic features and processes.

The first systematic survey of the physical oceanography of Atlantic Canada undertaken by Canada was the 1914 -1915 Canadian Fisheries Expedition (Bjerkan 1919, Sandstrom 1919) led by Dr. J. Hjort, Director of Fisheries for Norway. This was the beginning of efforts to relate fisheries variations to changes in oceanographic conditions. Throughout the 1920s and 30s, physical oceanography was an integral part of the fisheries related research programs carried out by federal fisheries laboratories in Atlantic Canada, especially at the St Andrews Biological Station.

The St Andrews Biological Station began as a small floating laboratory in the summers of 1899 and 1900. The laboratory was operated in subsequent summers in various locations in both the Maritimes and Quebec before a permanent laboratory was established at the present site in St Andrews, NB in the summer of 1908. During its early years, much of the science was conducted only during the summers by researchers from Canadian universities. The work of the station included physical oceanography from at least as early as 1914 when a hydrographic section was occupied in the Bay of Fundy (Craigie 1916). In 1921, the station began making daily sea surface measurements, a practice that has continued to this day with notable gaps in 1985/86 and 2001/02. This is Canada's longest record of coastal ocean temperature (Fig 2), exceeded only by the record from Booth Bay Harbor, Maine which began in 1906.

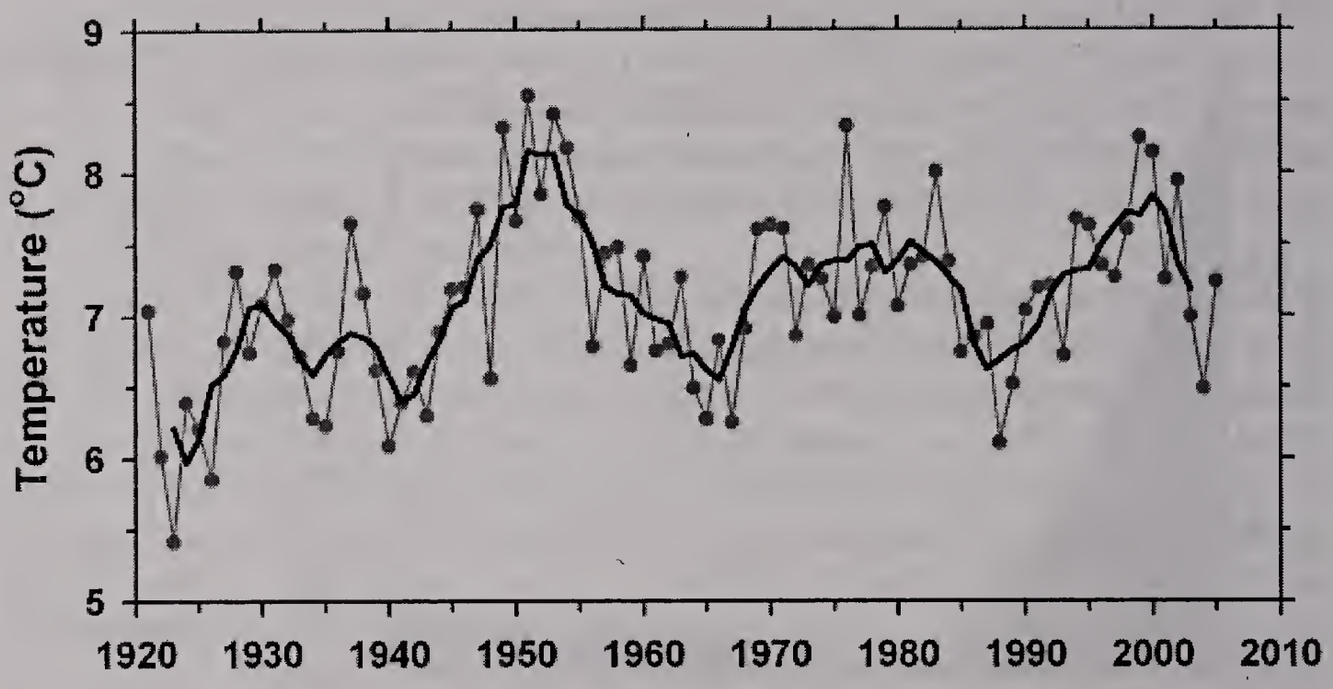

Fig 2 Sea surface temperature at St Andrews, New Brunswick. The annual average temperatures (grey dots, line) and the 5 year averages (heavy black line) are shown.

A Canadian pioneer in the physics of the oceans, Dr Howard Turner Barnes of McGill University, published, from 1906 through to 1929, a number of studies on the impact of icebergs on sea and air temperatures and on marine organisms as well as exploring ways to detect and destroy icebergs at sea. During the First World War, he also provided advice on the detection of submarines.

Physical oceanography in Atlantic Canada was strengthened when HB Hachey, then a member of the Department of Physics at the University of New Brunswick in Fredericton began in the late 1920s to spend his summers working at St Andrews (Campbell 1985). In 1930, he led the first research cruise into Hudson Bay, observing the water masses, currents, circulation, plankton and fish for the primary purpose of assessing its fisheries potential. Over the next three decades, Hachey wrote papers describing the regional oceanography of Atlantic Canada; the ideas developed in these papers still form the basis of our understanding of the ocean currents and circulation of Atlantic Canada (Hachey 1961).

The post World War II period saw a worldwide expansion of oceanography and Canada was no exception. The Canadian Committee on Oceanography, a body of senior managers of federal government and university departments with oceanographic capacity, planned and coordinated the remarkable growth of the Canadian Marine Sciences community. Institutes of Oceanography were established as graduate research organizations at the University of British Columbia and Dalhousie University to train Canadian oceanographers needed to support the creation of the new government laboratories and institutes.

Federal government physical, chemical and biological oceanographic and marine geophysical capacities in Atlantic Canada were significantly increased with the establishment of the Bedford Institute of Oceanography

(BIO) in 1962. At the time of its opening, BIO was occupied by scientists and hydrographers from both the Department of Mines and Technical Surveys and the Fisheries Research Board of Canada. It also supplied oceanographers to the Meteorological and Oceanographic Centre of the Canadian Navy and its programs often involved faculty and students from Dalhousie and other Canadian universities. This tradition of co-operation and collaboration across departmental boundaries functioned well, but was severely stressed by financial and organizational changes imposed during the program reviews of the 1990s. Fortunately, it still remains an important part of the way that oceanography is pursued in Atlantic Canada.

With the new BIO also came a fleet of one older and two new oceanographic / hydrographic vessels designed to work year round in the coastal and offshore waters of Atlantic Canada and the Arctic Archipelago. These included *Baffin* (in service from 1956), *Hudson* (1962) and *Dawson* (1970). Engineers, working with the physical oceanographers, developed deep sea and shelf mooring techniques that allowed self-recording current meters and thermosalinographs to be deployed for months to years at selected sites around the region. Over its first 25 years, BIO oceanographers mapped the water masses, currents and circulation of the North Atlantic from Bermuda and the Canaries to Svalbard, Ellesmere Island and the Arctic Archipelago. Canadian oceanographers and hydrographers carried out programs in the Caribbean, the tropical Pacific and Atlantic and even the Southern Ocean during the *Hudson* '70 circumnavigation of the Americas.

Halifax-Dartmouth is not the only centre of oceanographic expertise in Atlantic Canada. Oceanography has remained a part of the St Andrew's Biological Station program for more than a century. The Fisheries Station in St John's Newfoundland has also had a long history of observing and analyzing the variability of the physical environment of the Newfoundland and Labrador shelves; these activities are now part of the Northwest Atlantic Fisheries Centre programs. The government of Newfoundland has also made the study of the cold ocean a strategic priority with the result that Memorial University has built significant capacity in physical oceanography and ocean engineering over the past two to three decades.

The Gulf of St Lawrence is an important Atlantic Canadian marginal sea displaying many of the physical processes found in high latitude oceans. It has been an area of physical oceanographic studies since the tidal current surveys of *Dawson* at the end of the nineteenth century. Oceanographers at St Andrews and at the Bedford Institute of Oceanography continued to study the Gulf through to the 1980s. With the development of oceanography at the University of Québec at Rimouski and the establishment of the Maurice Lamontange Institute at Mount Joli, the responsibility for Gulf of St Lawrence studies was transferred to these Québec oceanographic groups.

Over the past one hundred and thirty years, oceanography globally and within Canada evolved through several different stages. In the early years, oceanography was exploratory consisting mainly of scientists taking a few widely scattered observations simply to observe some part of a largely

unknown ocean environment. This was followed by a systematic mapping phase. The third stage focused on observational, theoretical and modeling studies of particular oceanic processes. In my view, oceanography is just entering the fourth stage which consists of the routine operational production and delivery of ocean analysis and predictions to the marine and climate communities.

At the beginning of the twenty-first century, oceanography still pursues activities within all four stages, but new instruments and techniques open new areas and aspects of the ocean to our view. These are first explored extensively before being subjected to more complete observation and analysis. As the oceans are always changing, there must be systematic, ongoing mapping. These sustained observations are designed as part of ocean information systems in which observations feed ocean models which then produce analyses and maps directed to different marine users. As our understanding of ocean processes will always be incomplete, oceanographic research must continue. Increasingly, oceanographic research is directed towards interactions between the physical, biological and geochemical environment.

THE OCEAN'S ROLE IN CLIMATE AND WEATHER

The oceans cover 70% of the surface of the earth and consequently play an important role in the climate system (Fig 3) by storing and transporting

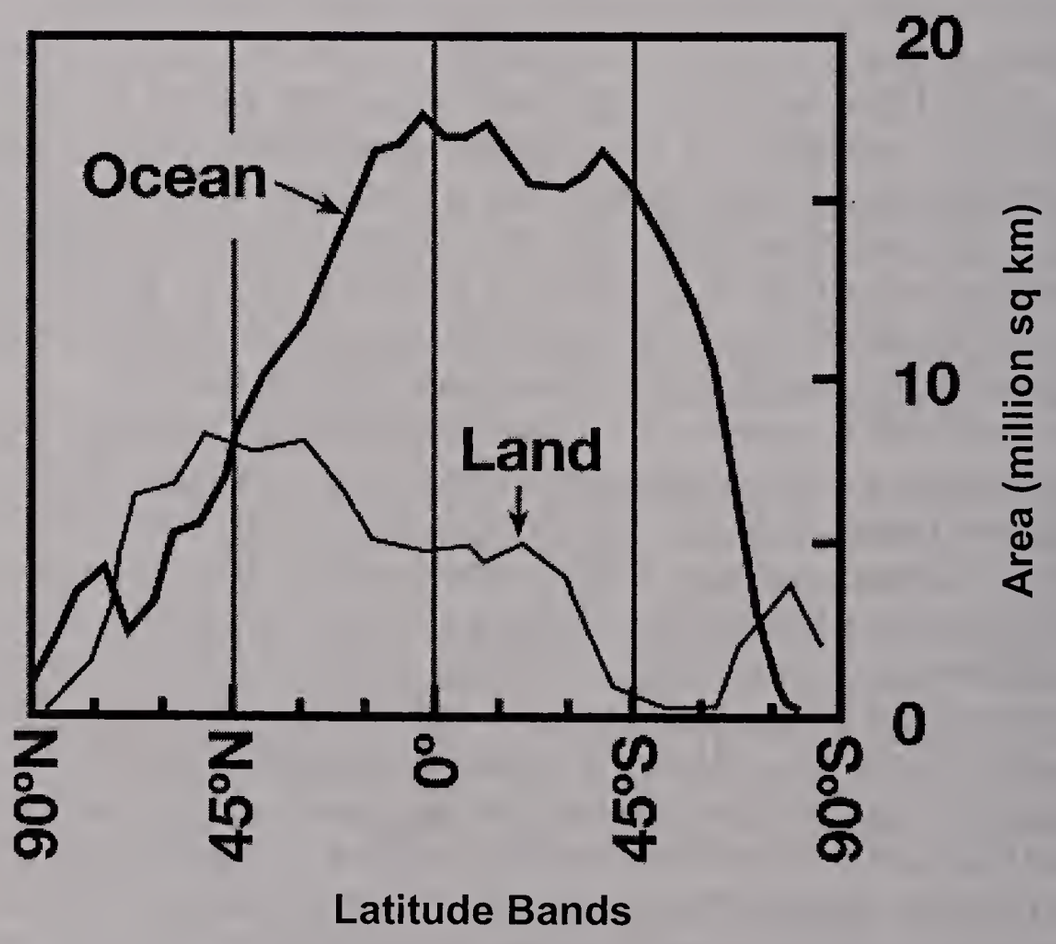

Fig 3 Zonal distribution of land and ocean.

large amounts of heat, water and radiatively active gases. These processes generally act to moderate changes in weather and climate. Temperatures over the oceans fluctuate less from day to night and from summer to winter than those found over the land; as one result spring warming is delayed, and so is fall cooling. Ocean processes cool the tropics and warm the higher latitudes making more of the globe favourable to life.

Ocean processes also support weather and climate variability and change. The warm waters of the tropical oceans generate tropical storms during summer and fall; warm ocean waters cause mid-latitude winter storms to strengthen explosively when the winds move from over land to over the ocean. Temperature anomalies in ocean surface waters are associated with large-scale climatic variability such as the El Niño Southern Oscillation (ENSO) phenomenon. Ocean processes are also believed to play key roles in the rapid changes of our climate system between glacial and interglacial states. Because of these important roles, Canada began in the 1990s to participate in the design and the implementation of a global ocean observing system for climate.

The climate system is driven by solar energy. When the climate is in a steady state, the earth radiates back to space all the energy that it receives. Almost one third of the incoming solar radiation is reflected back to space by clouds, aerosols, the atmosphere and the earth's surface; nearly half is absorbed at the earth's surface leaving less than 20% directly absorbed by the atmosphere. The earth's surface, including the ocean, plays a dominant role in providing the energy that drives atmospheric dynamics, creating weather and atmospheric climate. Energy is transferred from the surface into the atmosphere through radiation, evaporation, transpiration and thermal conduction.

Much of the extreme weather in Atlantic Canada has an oceanic origin. In the late summer and fall, the region experiences tropical storms. These small but intense systems are born through convection over the warm (> 28°C) surface waters of the tropical North Atlantic and are carried westward toward the Caribbean and Gulf of Mexico by the trade winds. Some of these storms turn northward traversing the warm surface waters of the Sargasso Sea which, especially at the end of the summer, allow them to move northward for several days while retaining much of their energy. Most remain offshore where their strong winds and confused seas are a hazard to shipping and other marine activities. Other tropical storms come ashore in Atlantic Canada wreaking havoc with their high winds, elevated sea levels, large waves and heavy rainfall.

During the winter months, Atlantic Canada is subjected to large and intense storms that move eastward across North America south of the Great Lakes before moving out over the ocean between Washington and New York cities. When they move from the land to the much warmer ocean, these storms intensify quickly and move northeasterly toward and through Atlantic Canada and its offshore waters. The prediction of the magnitude of the intensification and their subsequent trajectory and development is a

challenge to the current weather models. Continued research on air-sea exchanges of momentum, heat and water vapour as well as improvements in the parameterizations of these processes in the weather forecast models continue to be pursued in Canada and elsewhere.

The forecasting of tropical and marine storms requires knowledge of the observed sea surface temperatures (SST), as these control the ocean / atmosphere exchange of heat and water vapour that will govern the development of the storm. For example, Hurricane Juan, in 2003, was able to sustain itself as a Category Two hurricane as it came ashore at Halifax because of the anomalously warm surface and upper ocean temperatures between the Gulf Stream and the coast of Nova Scotia. Currently, the SST field from satellite observations is included in weather forecast models. However, the storms extract large amounts of heat from the ocean to the atmosphere thereby cooling the ocean surface. The next generation of models will include information about the upper ocean so that the model can forecast the changing SST field and through this better predict the overall development of the storm. Since 2000, BIO oceanographers have maintained an array of autonomous instruments that provide the necessary real-time observations of the sub-surface temperature and salinity profiles from the Northwest North Atlantic as a Canadian contribution to a global array.

Over most of the world's oceans, only the uppermost 50 to 400 metres participate directly in the seasonal cycle of heat accumulation and release. Only in a few restricted regions of the North Atlantic and the Southern Ocean do the dense waters that fill the ocean depths come in contact with the atmosphere. One of these regions is in the Labrador Sea just outside Canadian waters. Because Canada's oceanographic vessels were capable of working in ice and winter conditions, it was not surprising that the study of the transformations of these deep waters has become an area of special Canadian interest and expertise. The winter survey of the entire sub-polar gyre of the North Atlantic in 1965 – 1967 (Fig 4) has remained the definitive description of this regime for fully 3 decades (Grant 1968). Understanding these processes is an important part of understanding the oceans' role in the climate system.

The oceans are also important reservoirs of all the significant greenhouse gases produced and found in the lower atmosphere. For example, the oceans contain 1000 times more carbon dioxide than does the atmosphere. The upper ocean exchanges about 100 gigatonnes of carbon in the form of carbon dioxide with the atmosphere during the seasonal cycle. About 100 gigatonnes flows from the atmosphere to the oceans when the surface ocean is being cooled or where carbon dioxide is being consumed by biological primary productivity while 98 gigatonnes flows back to the atmosphere when the ocean surface warms and biological primary productivity is suppressed. The net annual storage of 2 gigatonnes of carbon represents about a third of the 6 gigatonnes of carbon released by human activities such as burning fossil fuels and carrying out large-scale land use changes. Because the ocean is such a large reservoir of carbon dioxide,

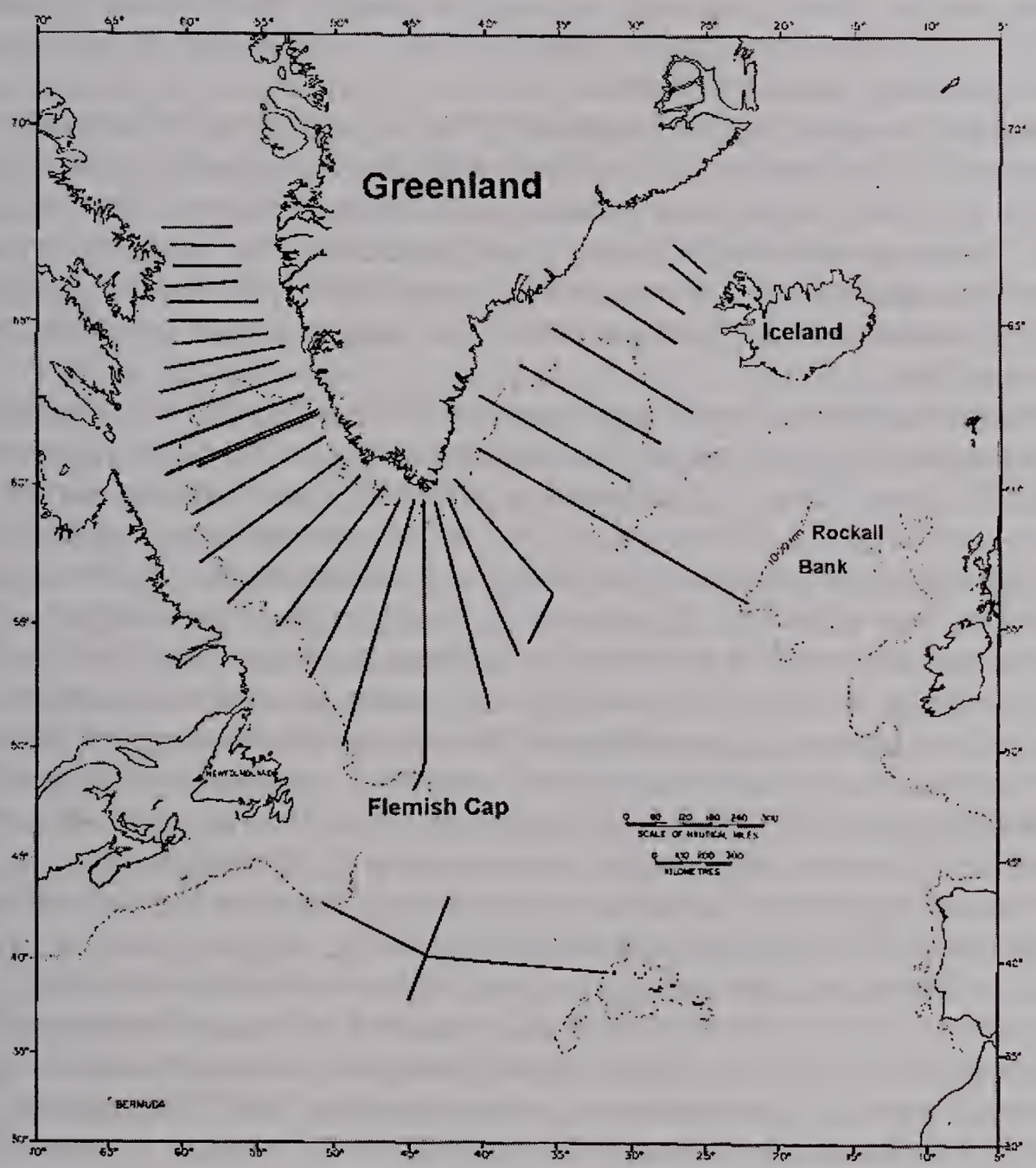

Fig 4 BIO's Sub-polar gyre survey, 1965-1967 (adapted from Grant 1968). Full depth hydrographic stations measuring temperature, salinity and oxygen content were occupied along each of the sections. Silicate and phosphate were measured on many of the stations. Surveys were conducted by CGGS Labrador, CSS Hudson and CSS Baffin.

changes in the oceans' surface temperatures, such as those occurring during El Niño years, result in variable uptake of CO_2 and hence modifying the rate of increase of atmospheric CO_2.

During the 1990s, the global oceanographic community carried out the World Ocean Circulation Experiment (WOCE). The goal of this experiment was to develop the global ocean models needed to improve our predictions of climate change as well as to collect the high quality global data set necessary to test those models. Over eight years, oceanographic vessels from all of the major nations of the world spent more than 3000 months at sea occupying a series of north-south and east-west sections across every major ocean basin other than the Arctic Ocean. Measurements of the

distribution of radioisotopes and modern industrial chemicals along these sections provided new ways to estimate the strength and time scales of the slow, deep, circulations of the ocean.

Atlantic Canadian oceanographers deployed current meter mooring arrays to measure the transport of the North Atlantic Current east of the Grand Banks of Newfoundland and to observe winter convection in the Labrador Sea. Oceanographic sections were occupied across the Labrador Sea and east of Newfoundland. Oceanographers from BIO and Dalhousie University joined American and British scientists in a study on mixing in the ocean thermocline.

Several new technologies were deployed during WOCE. By use of satellite altimeters, a global map of the height of the sea surface was generated every 10 days. This is equivalent to the meteorologist's map of surface air pressure and allows the oceanographer to estimate the strength of the large scale surface currents. A satellite instrument called a scatterometer was also deployed during WOCE. By measuring the strength of the shortest waves on the sea surface, this instrument estimates the magnitude and direction of the surface wind which primarily drives the ocean surface circulation. For the first time, oceanographers had real-time global observations of both wind forcing and strength of the surface circulation. In addition to these satellite observations, WOCE developed and deployed surface and deep drifters to measure the current field at the sea surface and 1500 metres.

The rapid growth of computer power greatly assisted the development of global ocean circulation models during WOCE. By the 2000s, computers were large and fast enough to support global ocean models that could resolve most of the relevant physical processes, at least at low and middle latitudes. Improved computer technology also allowed scientists to analyze the large oceanographic data sets, collected during WOCE and earlier, and create appropriate fields to initiate, force and verify these models. This development led to the next generation of coupled atmosphere – ocean models that have been used to generate the climate change projections that formed the basis of the 2001 assessment of climate change performed by the Intergovernmental Panel on Climate Change.

THE OCEAN ENVIRONMENT IN MARINE ECOSYSTEMS AND FISHERIES

With good reason soon after they began to fish, humans became concerned with the rise and fall of their catches. The history of commercial fisheries is full of examples of vigorous fisheries collapsing to near zero over short periods of time. Aggressive over-exploitation of the fisheries is likely to have played a significant role in these collapses, but paleo-climatic studies also have shown similar patterns existing before commercial fisheries arose (Baumgartner et al. 1992, Finney et al. 2000). As mentioned earlier, the initial goal of large-scale systematic physical oceanography in Atlantic

Canada was to try to understand the role that ocean variability played in the changes in abundance of commercially important species.

Temperature, salinity, nutrients, solar radiation, waves, currents, trace chemicals, bathymetry and bottom characteristics all play important roles in the health of marine ecosystems at different times within their biological cycles. The marine ecosystem begins with the fixing of carbon dioxide through photosynthesis by phytoplankton and other marine plants. This process is affected by temperature and nutrient concentrations as well as light levels, the stability of the water column and its turbulent energy. Under conditions of low stability or strong turbulence, phytoplankton cannot remain at their optimal light levels. On the other hand, if the surface layer is strongly stable, phytoplankton can rapidly deplete the nutrients because vertical processes such as upwelling and mixing that can replenish nutrients are strongly suppressed.

Higher trophic levels respond to the ocean environment in ways that we are just beginning to understand. By comparing the distributions of particular species with changes in ocean temperatures and salinities, fisheries oceanographers have developed some insight into the range of environmental conditions tolerated by those species. These investigations are complicated by the fact that the ocean environment likely affects marine species differently at each stage of their development. As the organism moves from the egg through various larval and immature stages to spawning adult, it will need particular environmental conditions for optimal growth and survival. During the early stages, ocean temperatures are important for growth and development rates while ocean currents are important to move the eggs and larvae from spawning to nursery areas. As the organism grows, ocean temperature still plays a role in its rate of development. Colder temperatures modify production and availability of food, slow the animal's physiology and hence reduce growth. Warmer temperatures can increase the stress on the animal and also increase the impact of disease and parasites. Specific marine organisms have been adapted to develop best at particular ranges of ocean temperatures; beyond certain thresholds both warmer and colder temperatures can decrease growth and survival.

Of course, a species does not live alone in the ocean. Its growth also depends on the availability of food organisms, the abundance of other species that compete for those same prey, and the concentrations of predators. All vary in response to the ocean environment. Because of this complexity, modern fisheries oceanographers are now focusing on entire marine ecosystem dynamics, rather than single species.

OCEANOGRAPHY IN SUPPORT OF MARINE INDUSTRIES AND SAFETY AT SEA

When the oil and gas industry began exploring in the offshore waters of Atlantic Canada and the Eastern Arctic, their representatives contacted the physical oceanographers for information on the sea-ice, iceberg and

wave conditions and ocean currents that would be encountered. Offshore structures and operations have to be designed to withstand the strongest waves and currents that are likely to occur in the desired areas. Compilation and analysis of archived data provided the initial basis, but many new observations were collected to provide site-specific data for the design of both the exploration drilling platforms and the later production facilities. Offshore operators need real-time knowledge of the waves and currents in order to safely carry out critical tasks associated with drilling, supply to the platforms and installation of production infrastructure. When accidents occur, with people or oil slicks possibly adrift, data on the ocean currents are needed to predict their movement and to plan their recovery. The initial physical oceanographic support to the oil and gas industry was provided by BIO; however, during the 1970s the development of a number of private sector oceanographic groups, through collaboration with both government and university scientists, soon provided a full range of observational and modeling services to industry.

Ocean currents are complex and difficult to measure accurately. They arise from the tides, from the local wind, from the large-scale wind and circulation and from various eddies and planetary waves that might be propagating through the area. They also vary with depth and time. Observing ocean currents is an expensive and time-consuming process because they vary over time scales of minutes to years, and thus observations must be collected over several years to begin to define even the annual cycle. As a result, oceanographers have turned to ocean models to complement their observations.

Ocean modeling is a rapidly developing tool to produce analyses and forecasts based on the data. New research models, however, must be regularly evaluated against the existing operational models under simulated operational conditions at sea. These models, able to simulate the effects of tides, winds, bathymetry and the large-scale ocean circulation for selected regions and to provide real-time estimates and predictions of ocean currents at various depths are used for large engineering projects in the offshore and during marine emergencies. An example was provided by the salvage operations following the crash of Swiss Air flight 111 in September 1998 which were hampered by strong and variable currents over the crash site. BIO oceanographers quickly created a local ocean model driven by tides and wind forecasts that predicted both surface and subsurface currents throughout the region. These predictions were used successfully to plan each day's operations (Fig 5).

The ocean instrumentation industry of Nova Scotia has developed a number of radio and satellite tracked drifters that simulate the drift of oil slicks or survivors in life jackets, survivor suits or life rafts. These have been used in a series of exercises to test the capabilities of the ocean models in the waters off Nova Scotia. The drifters are deployed by aircraft in Search and Rescue and marine environmental incidents to provide on site observations

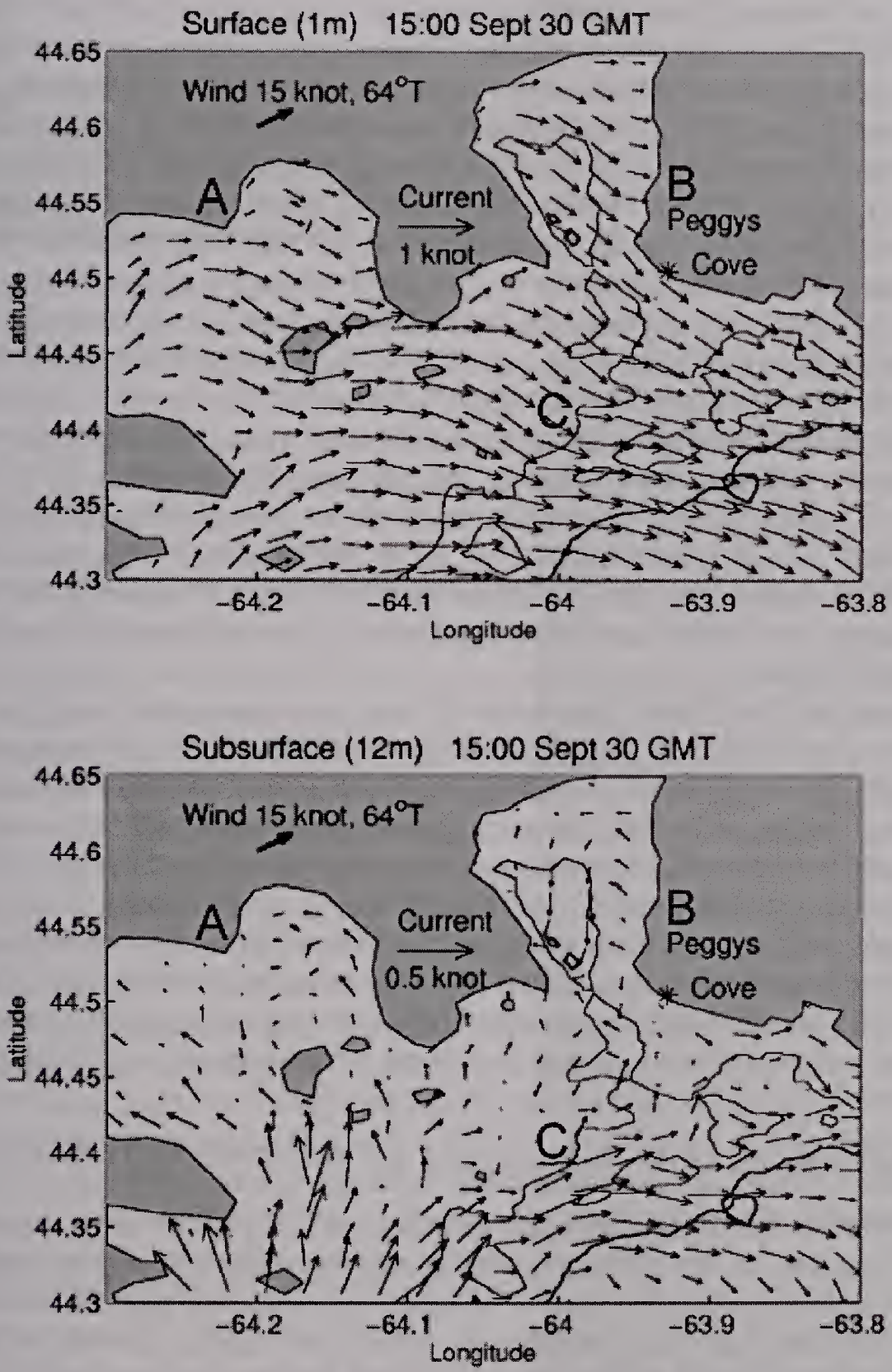

Fig 5 Predicted tidal currents produced for the salvage operations following the crash near Peggy's Cove, Nova Scotia of Swiss Air flight 111, September 2, 1998. The crash site is point 'C'; 'A' and 'B' are Mahone and St. Margaret's Bay respectively.

of the ocean currents to directly simulate drifting objects and support the ocean model predictions.

Technology exists that will provide continuous real-time estimates of the surface currents up to 200 kilometres from shore. High frequency systems known as Coastal Ocean Dynamics Application Radar (CODAR) consist of

small transmitter / receiver stations sited on headlands or offshore islands every 150- 200 km along a coastline. These systems provide surface current and wave information at 3 km resolution over the continental shelf. Such a system is being established as part of the Gulf of Maine Ocean Observing System (GoMOOS) (http://www.gomoos.org/). CODAR transmitters on Green Island, Maine and Cape St Mary, Nova Scotia provide hourly estimates of the surface currents in the northeastern Gulf of Maine. Additional stations are planned so that eventually the entire Gulf will be covered. Canadian members of GoMOOS include the Atlantic Pilotage Authority, Bedford Institute of Oceanography, OEA Technologies, St Andrews Biological Station, Saint John Marine Pilots and Satlantic Inc. The project also includes instrumented moorings measuring currents, winds waves, temperature, salinity and optical properties at selected sites throughout the Gulf. These data are reported back to shore in real-time and are combined with CODAR and satellite data. The combinations are used directly and to drive ocean models that provide information on waves, currents, temperatures and water quality to a variety of marine interests throughout the Gulf of Maine.

Over much of the US continental shelf, regional ocean observing systems such as in the Gulf of Maine are being established through partnerships among federal, state and academic agencies. The regional structure is necessary because the design and operation of these systems is still an area of active research. User needs from region to region differ and this will influence the regional designs. However, the American goal is to combine these regional systems into a national one that will provide real-time ocean data to support marine operations and marine and environmental safety over all US national waters. Ocean information will be available at the click of a mouse to responders to future marine emergencies in US waters.

OCEANOGRAPHY IN SUPPORT OF INSHORE ACTIVITIES

Inshore environments such as harbours, embayments and shorelines present special challenges to physical oceanographers. Local topography and bathymetry affect the winds and currents on spatial scales far smaller than any regional operational model can hope to deliver. In these shallow environments, issues related to the accuracy of the chart datum and changes to water depths and shorelines resulting from sedimentation, shoreline erosion, dredging and shoreline development become very important. Many of the bays and inshore waters of Atlantic Canada, particularly in Newfoundland and Labrador, have not even been surveyed by modern hydrographic methods. For heavily used environments, it is critical to develop the expertise and tools to observe and model waves, currents, tides and water quality in order to reduce impacts of multiple uses.

Much inexpensive instrumentation is available for use in shallow waters and can be mounted easily on jetties, aquaculture cages and light moorings that can be deployed from small boats. Because the instruments are moored

close to land, their data often can be brought ashore via radio or cell phone links or through underwater cables. However, these environments are also biological hot spots or subject to high levels of human traffic. Instrument failure caused by biological fouling or vandalism is a frequent occurrence. In Atlantic Canada, we also have the problem of freezing in much of our coastal environment. This means that moored real-time systems cannot rely on a surface float and radio communication through the winter months; underwater cables must be protected from sea ice scour at the shoreline.

Because the equipment is relatively inexpensive and easy to use, a number of individuals make regular oceanographic measurements for their own purposes. Operators of lobster pounds, aquaculture sites and thermal power plants regularly measure ocean temperatures and perhaps other parameters such as salinities or oxygen concentrations. Few of these observations are documented or archived to contribute to an overall understanding of the climatology of the Atlantic Canada inshore environment. The Department of Fisheries & Oceans (DFO) developed a program in the 1970s to measure coastal water temperatures at sites around Atlantic Canada. The data collected have allowed the climatological seasonal temperature cycle in the upper 12 metres to be produced for all of the North Atlantic Fisheries Organization (NAFO) sub-areas of Atlantic Canada. This climatology is available from the website address: http://www.mar.dfo-dpo.gc.ca/science/ocean/coastal_temperature/coastal_temperature.html

While these coastal temperature data provide basic information needed to design a water intake for a lobster pound or a power plant, they do not help with day-to-day operations. Measuring the temperatures at the intake, allows the operator to respond to varying conditions, but provides no warning of approaching changes. Real-time observing systems can be designed and integrated with ocean models so that operators could get several days warning of the possible onset of adverse conditions that could impact their operations.

Pilot observing systems have been established as research projects in a few selected embayments. Dalhousie University's Centre for Marine Environmental Prediction is running such a program in Lunenburg Bay. An array of weather stations and instrumented oceanographic buoys around this coastal embayment is providing real-time data to a fine scale coupled atmosphere – ocean model of the system. While this is a research project, it was used in a quasi-operational way during the World Youth Sailing Championships in July 2002 to provide detailed analyses and predictions to the competitors of both winds and currents.

CONCLUSIONS

Physical oceanography over its first twelve decades has developed the theoretical understanding as well as the observational, analytical and modeling tools to design and operate ocean observing systems that can deliver

reliable information from the open ocean, shelf seas and inshore environments. With existing technology, local ocean information systems are already being operated in support of a number of marine activities, e.g. vessel routing services, naval operations in the open ocean, ice management, platform control information, sea surface height and wave information. In Canada and other countries, research groups are capitalizing on these advances by developing and testing improved systems for these purposes.

Oceanographers in Atlantic Canada have been in the forefront of many of these developments. Because Atlantic oceanographers are a small community located within a handful of government and academic research institutions, the boundaries separating basic, targeted and applied research have not been as strong as on the larger oceanographic world stage. As a result many of the tools and techniques required for the new generation of ocean observing systems conceived by Atlantic Canadian researchers have been developed readily and directly into commercial products through partnerships with Atlantic Canadian companies.

Currently oceanography in Canada is at a crossroad. From the 1960s to the 1980s the federal government made a large investment, much of it in the development of the federal oceanographic laboratories and in the research fleet. During the deficit cutting of the 1990s, however, these resources shrank significantly. Scientists and technicians were not replaced when they retired, oceanographic instrument inventories have decreased and the fleet was reduced to a single 42 year-old multi-purpose vessel serving Atlantic Canada. At the same time, however, there has been some growth in the academic community in response to the government's Innovation Agenda which has allowed Canada to continue to carry out world class research projects on important oceanographic issues. However, because they are carried out largely by post-doctoral research fellows and students who leave at the projects' end, the projects tend to be relatively short-term.

Over the next decade, western Europe and the US will develop ocean observing systems covering most of their shelf seas. These will provide real-time ocean information to serve a variety of needs for marine and environmental safety, vessel and offshore operations, improvement of coastal and marine weather forecasts and fisheries management. The global ocean climate observing systems will still be providing observations on climate change and variability from the deep sea. If Canada is to continue to be a full participant in oceanography, it will need to reinvest in its oceanographic community by renewing its personnel, research fleet and instrumentation. As the oceans are a key component of the economy and life of Atlantic Canada, this oceanographic knowledge and information is needed so that the ocean resources can be used safely, co-operatively and wisely.

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BIOLOGICAL OCEANOGRAPHY IN CANADA (WITH SPECIAL REFERENCE TO FEDERAL GOVERNMENT SCIENCE)

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This is a personal account of the history, accomplishments and future of biological oceanography in Canada with emphasis on Canadian government research. Canadian biological oceanographers have a rich history pre-dating the formal beginning of marine scientific research in the country with the establishment of the St Andrews and Nanaimo field stations in the early 1900s. Over the years, they have distinguished themselves by being leaders in the early developments of the discipline, including methodologies, concepts and understanding of both the pelagic and benthic ecosystems. In more recent years, Canadian biological oceanographers have led in the conceptualization, planning and implementation of major interdisciplinary/international research initiatives on climate change and ecosystem dynamics. Additionally, they are making important contributions to ecosystem and climate monitoring, research aimed at understanding the influence of ecosystems on harvestable living resource variability and on climate change, and development and application of ecosystem and climate models. Canadian biological oceanographers have made and continue to make significant contributions to the understanding of the biology of the oceans and its interactions with the physical, chemical and geological world. The challenge of solving the complex scientific and societal problems of the future will require better planning, coordination and stronger commitment to the ocean sciences by universities and government than is currently in place. Strategic planning to define goals and responsibilities is urgently needed and should include not only government and universities, but also private sector research and industry.

Ceci est une vue personnelle de l'historique, des réussites et de l'avenir de l'océanographie biologique au Canada qui met l'accent sur la recherche gouvernementale canadienne. Les océanographes biologiques canadiens ont un passé riche qui pré date le début officiel de la recherche scientifique marine dans ce pays avec la fondation des stations marines St. Andrews et Nanaimo au début des années 1900. Au fil des ans ils se sont distingués par leur rôle de chef de file dans le développement de cette discipline, couvrant les méthodes, les concepts et la compréhension des écosystèmes pélagiques et benthiques. Les océanographes biologiques canadiens ont mené dans la conceptualisation, la planification et la mise en place d'initiatives majeures en recherche multidisciplinaire et internationale sur le changement climatique et la dynamique des écosystèmes. De plus, ils font actuellement des contributions importantes à la surveillance du climat et des écosystèmes, à la recherche visant à comprendre l'influence des écosystèmes sur la variabilité des ressources marines exploitables et sur le changement climatique, et au développement et à l'application des modèles climatiques et écosystémiques. Les océanographes biologiques canadiens ont fait (et continuent à faire) des contributions significatives à notre compréhension de la

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biologie des océans et de ses interactions avec la physique, la chimie et la géologie. Les défis soulevés par les problèmes scientifiques et socio-économiques complexes de l'avenir exigent une meilleure planification et coordination et un engagement plus fort envers les sciences océaniques que démontré présentement par les universités et les gouvernements. Il est urgent de développer une planification stratégique qui définit les objectifs et les responsabilités pour rencontrer les défis de l'avenir et qui inclue non seulement les gouvernements et les universités, mais aussi la recherche privée et l'industrie.

INTRODUCTION

Biological oceanography is one of the four cornerstones of the field of oceanography; the others are geological, physical and chemical oceanography. There is often confusion about exactly what constitutes biological oceanography. Marine biology, the study (physiology, behavior, etc.) of organisms of marine origin, is most often associated with the term biological oceanography. However, biological oceanography is concerned more with the interactions of marine organisms among themselves and with the physical, chemical and geological processes of their environment rather than with the study of individuals. Biological oceanography, indeed, is the multidisciplinary study of the ecology of the oceans. Parsons et al. (1984), in their popular book on this subject, indicate that the "biology" considered in biological oceanography includes not only the plankton (bacteria, phytoplankton, zooplankton, invertebrate and vertebrate larvae) of the inshore, coastal and oceanic pelagic zones, but also the benthos. They go further to suggest that fisheries oceanography could also be included in the broader definition of biological oceanography. The curriculum for biological oceanography in most well-known North American universities, for example, includes courses such as: marine microbial ecology, phytoplankton ecology and marine primary production, zooplankton ecology, marine benthic ecology, etc. One course description states: "*Principles of Biological Oceanography – Lectures and discussion of the fundamental processes underlying primary and secondary production in marine ecosystems. Examples are drawn primarily from offshore systems. Emphasis on physical processes supporting primary production, plankton dynamics, biotic interactions structuring communities, vertical and horizontal distributions, foodweb structure, ecological role of higher and lower trophic levels, and benthic-pelagic coupling. The course concludes with a survey of the major oceanic ecosystems.*" Clearly, biological oceanography is broad in scope and interfaces with all of the major ocean disciplines. In fact, the term "biogeochemistry" (the processing, recycling, storage and transport/loss of chemical components within the marine environment, mediated by biological processes (Black & Shimmield 2003)) is in common use and illustrates how the distinction between biological oceanography and the other major ocean disciplines is becoming less well defined.

In this short review, I will place most emphasis on the plankton because this is the biological community with which I am most familiar; it in no way

diminishes the importance of the other biological communities of the sea. My intent is to describe briefly the origins of biological oceanography, how the discipline has developed and where it might be (or should be) going. My focus to a great extent will be on Canadian research and more specifically federal government science. I hope that the topics discussed, however, can be viewed in a broader context, applicable also to university as well as government science and with regional to global relevance.

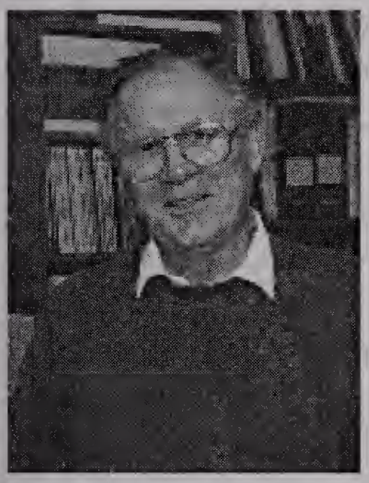

Fig 1
Professor T. R. Parsons

In 1975, Professor TR Parsons (Fig 1), University of British Columbia (UBC), wrote a review and perspective on biological oceanography in Canada for the Fisheries Research Board of Canada (Parsons 1975). This report provided a particularly comprehensive and insightful discussion of the status of Canadian biological oceanography up to the decade of the 1970s and will serve as a reference point for my observations, comments and conclusions. How much have we advanced in our understanding of the biology of the oceans in the last ~30 years? There have also been a number of studies published in more recent years that have identified the cumulative accomplishments in biological oceanography and speculated on where the field should be headed – driven by unanswered fundamental questions and societal needs. I will highlight some of that discussion in this review.

Finally, this review largely reflects my own personal perspective (and biases); any major omissions are not intentional and simply reflect my inability to keep pace with the accelerating growth of this discipline.

BEGINNINGS

Probably the best known and most comprehensive review of the origins and chronology of the development of biological oceanography as a discipline is that of Mills (1989). Although the biological observations made during the famous *Challenger* Expedition, 1872-76, are thought to have marked an important step in the development of biological oceanography, research begun years earlier in European, especially German and Scandinavian laboratories, is credited with establishing biological oceanography as a quantitative science. Motivated not only by scientific curiosity, but also by a desire to understand how changes in the ocean environment might be contributing to declining regional fish stocks, scientists in the eastern North Atlantic began detailed studies of the distribution, composition and productivity of marine plankton starting in the early to mid-1800s. Notable among members of the Kiel Group were: (1) Victor Hensen who coined the term "plankton" and was among the first to propose a link between plankton production cycles and fisheries, (2) Hans Lohmann who first described the annual cycle of plankton from his studies in Kiel Bight and described

the succession of species over the year, (3) Karl Brandt who developed early ideas about nutrient control of plankton cycles and productivity, and (4) Alexander Nathansohn and (5) H.H. Gran who proposed that ocean circulation (mixing and stratification) and light had a strong influence on the distribution, seasonal cycle and production of plankton in the ocean. A synthesis of many of these ideas and concepts was captured in Murray and Hjort's milestone textbook, "The Depths of the Ocean", published in 1912. Significant also about this time was the formation of the International Council of the Exploration of the Sea (ICES), primarily for the purpose of applying oceanographic research to fisheries problems. Johan Hjort and Harald Sverdrup were instrumental in establishing ICES as a credible instrument for fisheries research and, with its specialized research fleet, for integrating oceanographic observations with fisheries in a systematic way (Stewart 1991).

Following the advances made by the Kiel Group in developing the ideas and foundations of modern biological oceanography, scientists at the Plymouth Marine Lab in the United Kingdom (UK), through the use of refined methodology and more detailed observation in the field and lab, established indisputable evidence of the importance of nutrients, light and community interactions (grazing) on the dynamics of plankton populations. Important players in the Plymouth Group were: Atkins, Harvey and Cooper who elucidated the cycles of inorganic and organic nutrients (phosphorus and nitrogen) and their link to phytoplankton growth, Atkins and Poole who developed new instrumentation and experiments to demonstrate light limitation of phytoplankton growth and Harvey, Cooper, Lebour and Russell who described the connections between phytoplankton and zooplankton growth cycles and revealed the role grazing plays in the decline of phytoplankton blooms. With a near complete picture of the plankton foodweb in quantitative terms, Harvey reasoned that it should be feasible to describe the dynamics in mathematical terms and thus introduced modelling to the field of biological oceanography.

If Harvey and colleagues were first to explore the utility of mathematical modelling, the United States (US) group and UK colleagues, led by notable figures in the 1940s and 1950s such as Gordon Riley and John Steele, developed the tool of modelling in biological oceanography to the level of a discipline in itself. These early models provided the foundation for the sophisticated, coupled biogeochemical – circulation models in use today to help understand the global ocean carbon cycle and its role in climate change (Doney et al. 2002), and for ecosystem models used to help understand better the dynamics of plankton populations in coastal waters and the influence of ocean physics on higher trophic levels (Weibe et al. 2001). The basic questions, approaches and tools used by these early biological oceanographers are still in use.

The history of the development of biological oceanography in the western Atlantic, and Atlantic Canada specifically, has been well summarized in two reviews (Hachey 1961, Colton 1964). Probably of singular importance to

the development of ocean sciences in Canada was Professor EE Prince's (Commissioner and General Inspector of Fisheries of Canada) efforts to establish two marine science laboratories in the early 1900s, one in St Andrews, New Brunswick, the St Andrew's Biological Station (SABS) (Fig 2) and one in Nanaimo, British Columbia, the Pacific Biological Station (PBS). At about the same time, Norwegian fisheries surveys in the NW Atlantic led by Hjort and Murray included oceanographic observations in Atlantic Canadian waters. A few years later, Hjort was commissioned by the Canadian Marine and Fisheries Department to lead a more extensive survey, the major Canadian Fisheries Expedition of 1915. Starting in the early 1900s and continuing into the 1940-50s, extensive oceanographic studies were carried out in the Gulf of Maine and adjacent waters, and included circulation/hydrography, chemistry, phytoplankton, zooplankton, benthic fauna, fisheries and geology. Prominent among the oceanographers of that time were Bigelow, Clarke, Redfield and Riley. In the 1950s and 1960s, Dunbar, Grainger and Bursa made the first biological oceanographic observations in the Eastern Canadian Arctic (Parsons 1975).

Fig 2 St Andrews Biological Station (SABS), main laboratory 1908

In 1962, the Canadian government (through the then, Department of Mines and Technical Surveys) constructed the Bedford Institute of Oceanography (BIO) in Nova Scotia, Canada's largest oceanographic institution. Over the past 4 decades, BIO has been a major centre of biological oceanographic research, most notably in studies of the distribution, physiology and production of phytoplankton and zooplankton (Clarke et al. 2003). On the west coast, a research program at PBS under the leadership of John Strickland, Tim Parsons and colleagues, was developed to understand better the link between the environment and fish and established the foundations for standard biological and chemical oceanographic measurements (Strickland & Parsons 1972) and for contemporary tropho-dynamical studies of the plankton in the ocean (e.g. Parsons & Lalli 1988, Harrison & Parsons 2001). Without question, his textbook on biological oceanography (Parsons et al. 1984),

in its third printing, remains the best known and most widely used resource for training biological oceanographers at the university level. Biological oceanographic research on the west coast has now largely moved to DFO's oceanographic facility, the Institute of Ocean Sciences (IOS) in Sidney, British Columbia. The department's laboratory, the Maurice Lamontagne Institute (MLI) in Mont-Joli, Québec, is its newest major oceanographic research centre. Oceanographic research is also done, but to a lesser degree, at DFO laboratories in Newfoundland (Northwest Atlantic Fisheries Centre, NWAFC) and New Brunswick (Gulf Fisheries Centre, GFC). At the same time that biological oceanography was gaining a foothold in government laboratories, Canadian universities were building strong departments and educating an impressive cadre of professionals, many of whom have had a significant influence on the development of the field (e.g. Louis Legendre, currently Directeur du Laboratoire d'océanographie de Villefranche-sur-Mer, France). Major university oceanographic centres are found at or associated with: the Universities of British Columbia, Victoria, Guelph, McGill University, Laval Université, Université du Québec à Rimouski, Dalhousie University and Memorial University.

ACHIEVEMENTS TO DATE

The Canadian perspective

Tim Parsons, in his review of the status of biological oceanography in Canada in the mid-1970s and its interactions with other ocean disciplines, identified strengths and weaknesses in our research programs, infrastructure and training and offered a number of recommendations (Parsons 1975). It is instructive to review those recommendations and comment on what progress has been made in the intervening 30 years and to comment on what should be the burning questions for the future.

Parsons described a number of problems in biological oceanography where knowledge of the physical properties of the ocean could provide answers. However, he characterized the interactions of researchers in the two sub-disciplines (in the mid-1970s) as minimal. Thirty years later, the situation has improved considerably. Training at the graduate level by-and-large exposes students of biological oceanography to the allied disciplines (physics, chemistry, geology, fisheries) in a more systematic and comprehensive way. Multidisciplinary research projects at the regional, national and international levels are now the rule rather than the exception. For example, the international Global Ocean Ecosystem Dynamics program (GLOBEC) (Barange & Harris 2003, http://www.pml.ac.uk/globec/main.htm), and the more recent Ecosystem Studies In Sub-arctic Seas (ESSAS) (http://www.pml.ac.uk/globec/structure/regional/essas/essas.htm) program in which Canada has played a leading role, address on the climate scale the variability of ecosystems driven by physical processes. Activities in ocean modelling, similarly, reflect the merger of disciplines; regional ecosystem models are now driven by sophisticated mixed-layer dynamics and global

general circulation models commonly include biological sub-models (Doney at al. 2002, Denman 2003).

The same can be said for the current interactions of biological and chemical oceanographers compared with 30 years ago. As mentioned earlier, what might be referred to as a new discipline, biogeochemistry, has emerged from the collaboration of biological and chemical oceanographers addressing common problems related to climate change and the global elemental cyles (carbon, nitrogen, phosphorus, sulfur, etc.). A number of international research initiatives with strong Canadian participation have reflected this merger of disciplines. The Joint Global Ocean Flux Study (JGOFS) (Fasham 2003, http://www.uib.no/jgofs/jgofs.html) was a 20-nation, decade-long multidisciplinary program aimed at assessing more accurately and understanding better the processes controlling regional to global and seasonal to interannual fluxes of carbon between the atmosphere, ocean surface and interior, and their sensitivity to climate changes. A more recent international program, the Surface Ocean – Lower Atmosphere Study, (SOLAS) (IGBP 2003, http://www.uea.ac.uk/env/solas/), builds upon what was learned from JGOFS to develop a better quantitative understanding of the key biogeochemical-physical interactions and feedbacks between the ocean and the atmosphere, and how this coupled system affects and is affected by climate and environmental change. The newest international research initiative, the Integrated Marine Biogeochemistry and Ecosystem Research program (IMBER) (http://www.igbp.kva.se/obe/IMBERSP-IS-15Jan04.pdf), aims to improve the understanding of ocean biogeochemistry by considering the influence of ecosystem structure; it also has representation from the Canadian oceanographic community.

Within biological oceanography itself, interactions among specialists in different components of the plankton community (viruses, bacteria, protozoans, micro-zooplankton) have helped to elucidate, for example, the intricacies of the "microbial loop", the process by which microbial mineralizers and their grazers reprocess dissolved organic and inorganic metabolic by-products for return to the pelagic foodweb (Azam et al. 1983). Plankton specialists and benthic ecologists have worked together in a similar way to provide new insights into benthic-pelagic coupling in coastal and continental shelf waters; Canadian scientists have been in the forefront of this area of research (Hargrave 1985).

Perhaps as a result of his career-long personal interest in the role of environment and ecosystems on fish population dynamics and fisheries, Parsons paid special attention in his 1975 review to the shortcomings of fisheries science and management theory of the day to adequately consider environmental effects in explaining fish stock variability, recruitment, growth and mortality. The example was provided of the gradual failure of fisheries due to climatic effects and the emergence of new stocks and of how understanding the biological oceanography of the sea is essential for predicting such changes. It was at about this time that Cushing's "match-mismatch" hypothesis (Cushing 1972) was published and showed promise

in explaining why the period of larval fish survival at first-feeding was critical for subsequent recruitment success of the species to the fishery. Unfortunately, the observational capabilities to test this hypothesis were inadequate then and as a consequence it remained a plausible, yet largely unproven, link between ecosystems and fisheries. Recently, the advent of satellite remote-sensing of ocean colour, which provides spatially and temporally synoptic fields of phytoplankton biomass, has permitted a re-examination of Cushing's hypothesis. Canadian biological and fisheries oceanographers have compared annual recruitment variability in haddock on the Scotian Shelf with variability in the timing of the spring phytoplankton bloom (Platt et al. 2003) and zooplankton reproduction (Head et al. 2005) and found a high correlation between strong recruitment years and early plankton growth. Further analysis (Head et al. 2005) showed that haddock larval hatch earlier than historical spawning periods during strong recruitment events and suggest that early spawning incurs survivability advantages. These are encouraging results that lend support to the match-mismatch hypothesis and open the door to research that may better establish quantitative connections between foodweb properties and fish dynamics.

Parsons proposed that biological oceanographers take a more active role in developing a better understanding of how ocean properties govern fish population dynamics. With this information, they could then generate suites of oceanographic "indices" through systematic ocean monitoring that could prove useful in explaining fish stock variability. Parsons' long interest in this approach has begun to bear fruit. In 2001, he was awarded the prestigious Japan Prize in Marine Biology for his contributions to the development of biological oceanography in general and specifically for his contribution to the concept of fisheries management based on the dynamics of fish and their oceanographic environment (Parsons 2004). In addition, growing interest within the international ocean resource management and conservation communities in ecosystem-based approaches (Turrell 2005) has highlighted the wisdom of Parsons' pursuits. Canada, and DFO in particular, is taking a leading role in the implementation of ecosystem monitoring, e.g. the Atlantic Zone Monitoring Program (Therriault et al. 1998), and in the development of a framework for ecosystem-based fisheries management (EBFM) that aims to incorporate oceanographic information into the resources assessment process (Sinclair et al. 1999, see also Halliday & Fanning 2006).

Finally, Parsons proposed a way in which tropho-dynamics principles may be used to understand how ecosystem characteristics might facilitate the prediction of fish stock variability and cited some research supporting that view. The widespread application of static mass-balance models such as ECOPATH (http://www.ecopath.org/) and its dynamic modules ECOSIM and ECOSPACE by Canadian university scientists in the past decade (Pauly et al. 2000), for example, has offered one approach for applying biological oceanography to fisheries problems. However, in his most recent comments on the future of biological oceanography, Parsons (2002) suggested that our current understanding of trophic transfer efficiencies is poor and

that better data, better parameterization and model integration should be priority areas of research.

At the time of Parsons' review, marine aquaculture in Canada was such a new industry that the nature and scope of oceanographic information requirements were largely speculative. He indicated, however, that water quality would certainly be an issue, requiring the expertise of biological oceanographers. In addition, advice would likely be sought on potential food sources (plankton) for cultured filter-feeding species and potentially deleterious effects from natural phenomena such as "red tides". Finally, site selection criteria might require information on ocean properties provided by biological oceanographers (e.g. productivity, trophic state, etc.). Speculation again translated to reality – the phenomenal growth of aquaculture in Canada over the past two decades has generated concern from environmentalists and resource managers about the availability, suitability and carrying capacity of coastal habitats to sustain the industry's growth. Canadian oceanographers are playing a major role in addressing all of these issues (DFO 2003, Hargrave 2005).

The growing concern about marine pollution in coastal waters and the role of biological oceanography in addressing this concern was the last environmental issue Parsons raised in his review. He believed that biological oceanographers' primary mission in pollution research is to characterize the various food webs in the marine environment, presumably including both those of healthy and impacted habitats. The international Controlled Ecosystem Pollution Experiment (CEPEX) program, conducted in Saanich Inlet, BC in the early 1970s, was based on this whole-ecosystem (mesocosm) approach (Reeve et al. 1982), but was sustained for only a few years. The need is clearly evident today. In addition to inshore industry-based pollution, the expanding offshore oil and gas industry off Atlantic Canada raises the concern about impacted ecosystems away from the shoreline. Increasingly, biological oceanographers are asked to address the environmental impacts of such activities on the planktonic and benthic ecosystems. In Canada, and Atlantic Canada in particular, expertise and research on the subtle effects of pollution on ecosystem components or whole communities are virtually non-existent, but the problems are of growing concern. Fortunately, mesocosm research is showing some resurgence.

In addressing the overall needs in Canada for biological oceanographic expertise, Parsons commented on the instrumentation, infrastructure and facilities required to sustain a significant contribution. Exploitation of new technologies was emphasized, including in-water towed bodies with capabilities to detect and enumerate plankton (particle counters, lasers, acoustics) and measure nutrient salts and above-water aircraft/satellite-based ocean sensors. Numerous examples can be provided where Canada has led over the last two decades in the R&D, commercialization and application of towed particle counters (Dessureault 1976, Herman 1988) and in the application and interpretation of aircraft and satellite-based remote sensing of ocean colour, as mentioned previously (Platt et al. 1995). Both activi-

ties, however, are seriously under-funded at present; Canada continues to lose ground as an international leader in these areas of R&D. In his most recent discussion on the future of biological oceanography, Parsons (2002) emphasized the need for integration of observations (now routinely collected using the technologies that were only on the drawing board at the time of his 1975 review) into dynamical models, i.e. biological oceanography now has the capability and must contribute to the growing field of "operational oceanography".

A clear Canadian example of progress towards that objective is the Lunenburg Bay Project in Nova Scotia (www.cmep.ca/bay). This project, entitled Interdisciplinary Marine Environmental Prediction in the Atlantic Coastal Region" involves the collaboration of university, government and private sector researchers. This multidisciplinary team is attempting to develop a real-time prediction capability for environmental phenomena in coastal embayments on the daily to weekly time scales and includes: waves, surface winds, upwelling/circulation and ecosystem response (e.g. algal bloom dynamics).

In summary, Parsons made a series of short and long-term recommendations to promote and secure biological oceanographic expertise in Canada. I have highlighted a few of these here. With regard to the short-term, he recommended that:

- *Biological oceanographers should become more involved in all aspects of fisheries research.*
  In the context of the current interest in ecosystem-based resources management, this would seem a particularly relevant recommendation today; however, efforts in the Canadian government or academia to address this point are modest at present, but growing. Within DFO, considerable redirection of effort and resources to support the ecosystem approach is underway.

- *Biological oceanographers should become more involved in pollution research.*
  This has had little discussion in Canadian government science circles or academia, although some relevant modelling work has been done recently (Rivkin et al. 2000, Khelifa et al. 2003). The growth of offshore oil and gas in Atlantic Canada and increased demands on DFO to provide the advice on environmental impacts makes this a relevant recommendation today; DFO currently lacks biological oceanographic expertise in this area.

- *Long-term monitoring programs to measure biological parameters should be started in certain critical marine areas, e.g. The Strait of Georgia, Gulf of St. Lawrence, Grand Banks.*
  In 1998, DFO implemented the Atlantic Zonal Monitoring Program (AZMP) which largely addresses this point (Fig 3); The Gulf of Saint

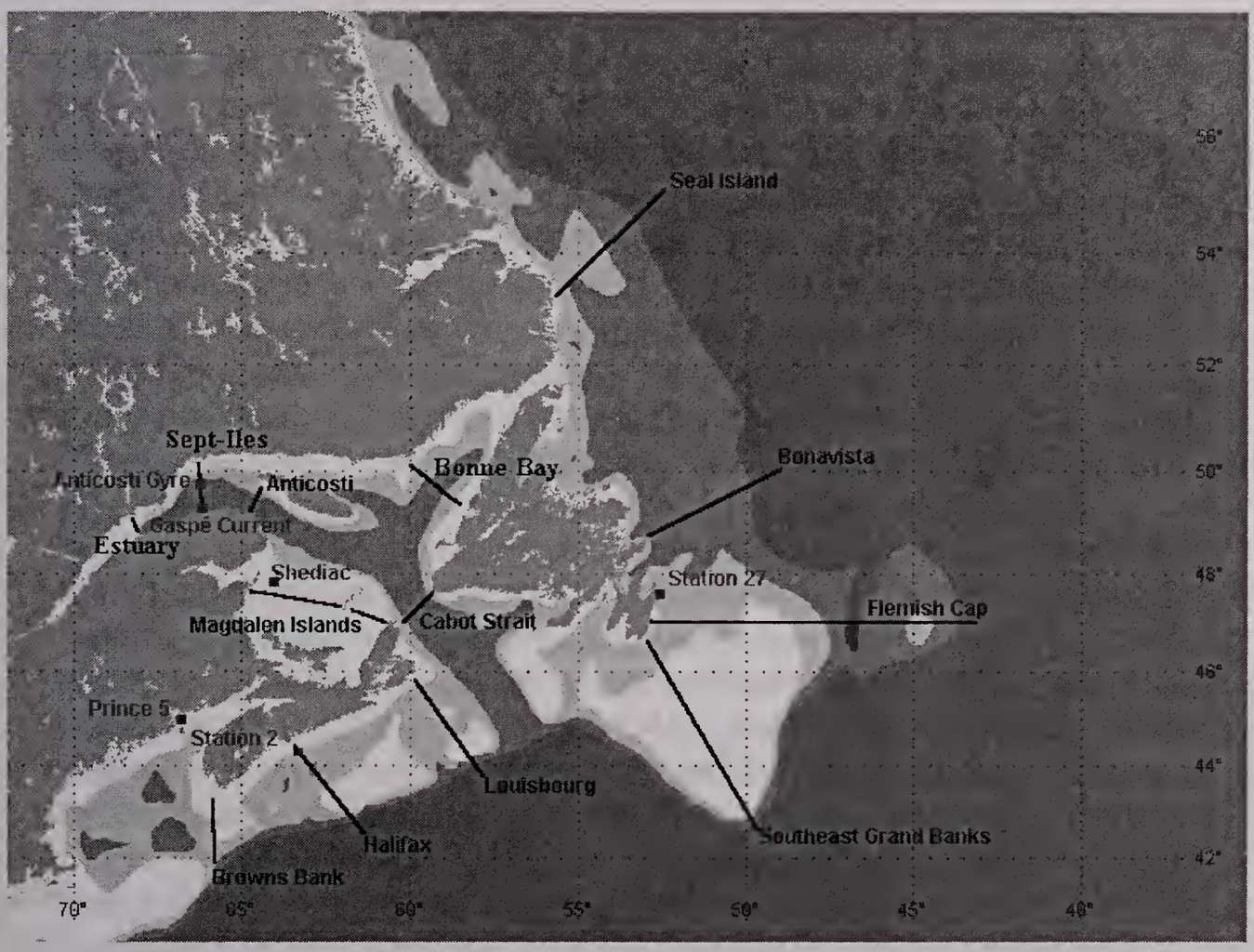

Fig 3 Sampling stations (point) and sections (line) - DFO's Atlantic Zone Monitoring Program, AZMP (Therriault et al. 1998)

Lawrence and Grand Banks are included in the more geographically-extensive monitoring program (Therriault et al. 1998). A formalized ecosystem monitoring program in the Pacific has not yet been implemented although a number of monitoring activities, e.g. OWS "PAPA" observations, have a long history. Planning is underway for a national monitoring network across Canada, as part of DFO's Climate Change Science strategy, that will include oceanographic observations in the three oceans bounding Canada: the Atlantic, Pacific and Arctic. This will, however, require a considerable investment of new or redirected resources.

- *Regional input of government funds in support of biological oceanography should be predicated on a clear demonstration of government, university and industry cooperation.*
  No new government funds within Canada for biological oceanography have been forthcoming. On the contrary, government scientists are being asked to continue to do more with less. Government, university and industry cooperation and resource sharing will be essential for maintaining a critical mass of biological oceanographic expertise in Canada. Biological oceanographic research within DFO has benefited greatly from partnerships and collaborations with Canadian and international

scientists (e.g. JGOFS, GLOBEC, SOLAS programs). The partnership between university and government must be continued and enhanced; however, it should be recognized that broad biological oceanographic expertise must reside in both institutions to address their complementary roles and responsibilities. Government must continue to take the prime responsibility for "public good" research such as ecosystem and climate monitoring and for the provision of major infrastructure support for national oceanographic research, i.e. sea-going research platforms (ships), to sustain a viable oceanographic (all sub-disciplines) capacity within Canada. Considerable investment of new funds will be required to revitalize the aging DFO oceanographic fleet.

- *More science is required in benthic ecology.*
  Canada's commitment to international conventions (e.g. on biodiversity), to the Canada Ocean's Act (where DFO has the mandate to identify and preserve representative marine habitats through the provision of Marine Protected Areas), and commitments to Ecosystem-based fisheries management (EBFM) mean that knowledge of the benthos in Canadian waters is essential. Although the application of new seabed mapping (multibeam) technology is being implemented by DFO and Natural Resources Canada (NRCan) to characterize benthic habitat in Canada's coastal waters (SEAMAP, http://seamap.bio.ns.ca/), DFO does not currently have the expertise nor has it committed the resources required to sustain a benthic ecology program.

Among Parsons' long-term recommendations were:

- *Better research facilities are required for the study of benthic communities, including provision for research and monitoring deep-sea benthos off the continental slope.*
  The joint Canada-US North-east Pacific Time-series Undersea Networked Experiments, NEPTUNE (http://www.neptunecanada.ca), cable-linked seabed observatory is relevant here. (See also short-term recommendation above).

- *Ecological information is needed on forage species (squid, small fish, euphausiids).*
  A similar recommendation was recently made by DFO's east coast Fisheries Oceanography Committee (FOC) to departmental senior management for consideration as an added observational requirement of the Atlantic Zonal Monitoring Program (AZMP). The lack of information on forage species also constitutes a huge gap in applying trophodynamic approaches to fisheries issues. The AZMP recommendation has not yet been acted upon.

- *Specific marine sites for biological research and aquaculture should be identified and held in trust for the development of experimental management strategies.*
  The provision in Canada's Oceans Act for Marine Protected Areas (MPAs) and DFO's Oceans Sector commitment to identifying and implementing MPAs in Canadian waters will go a long way toward addressing this recommendation. In addition, Canada's Centre for Marine Biodiversity (CMB) is working on the concept of "Discovery Corridors" (http://www.marinebiodiversity.ca/en/corridor.html) as a means of setting aside parcels of the ocean, free of exploitation, for research. A plan for the implementation of research and monitoring in these areas, i.e. who will do it and how will it be funded, has not yet been worked out.

- *Industry should explore the development of in situ biological samplers that can be used from commercial vessels.*
  DFO is currently working with academia and industry to adapt a number of oceanographic instrument packages for deployment from commercial shipping vessels and ferries, principally to support its ocean monitoring activities. Investment in technology is viewed as a means for increasing efficiency (i.e. by reducing reliance on conventional ship-based observations) and "operationalizing" oceanographic observations. As mentioned previously, however, DFO's resource commitments for technology are relatively modest and considerably reduced from levels of a decade ago.

- *More biological oceanographic work in the arctic is needed (with supporting physical/chemical oceanography).*
  Considering the vastness of the Canadian arctic and its importance in the global climate context among other issues, the commitment for arctic biological oceanographic research is modest at best. Canada, however, has taken a leading role in past as well as in new arctic research programs. For example, the international North Water Polynya Study (NOW) (Deming et al. 2002, http://www.fsg.ulaval.ca/giroq/now/wel.htm) brought together oceanographers from countries bounding the Arctic Ocean to improve understanding of the significance of polynyas as early indicators of the effects of climate warming at the poles. More recently, the Canadian-led international research network called Canadian Arctic Shelf Exchange Study (CASES) (http://www.cases.quebec-ocean.ulaval.ca/index.html), is investigating how the atmospheric, oceanic and hydrologic forcing of sea ice variability dictates the nature and magnitude of biogeochemical carbon fluxes on the edge of the Mackenzie Shelf. Canadian government and university biological oceanographers are playing an important role in both of these initiatives. In addition, the Canadian university sector has established a national centre of excellence for arctic research at Laval University, emphasizing climate impacts on the coastal Canadian Arctic (ArcticNet, http://www.

arcticnet-ulaval.ca), that will provide opportunities for collaboration with DFO science. Expanding research and monitoring in the north to address climate change issues have been identified as priorities in Canada, and commitments have already been made for partiicpation in The International Polar Year, 2007-2008 (IPY, http://www.ipy-api.ca).

- *Better research facilities (including ships) are required in support of arctic research.*
  Canada (and DFO in particular) as far as I am aware does not have plans for major infrastructure development aimed at enhancing oceanographic research in the arctic. However, a dedicated research vessel, the 98 m icebreaker CCGS Amundsen (http://www.amundsen.quebec-ocean.ulaval.ca), has been jointly funded by government and academia expressly for supporting Canadian arctic oceanographic research over the next decade.

One area in which biological (as well as physical and chemical) oceanography in Canada plays a significant role not explicitly covered in Parsons' review, is climate science. Science planning within DFO has not identified ocean climate research as an area for major investments in the next decade; it has been viewed as a national, but not necessarily a departmental high priority area. This I view as a strategic error since climate change will in all likelihood be the single-most significant societal issue in the coming decades (see previous section). It will undoubtedly have significant effects either directly or indirectly on the issues of sustainable development, resource management, habitat and biodiversity – all of which DFO identifies as top priority areas of interest. It may be viewed in some quarters that, within the government, other natural resources departments (e.g. Environment Canada (EC)) should (and can) provide the science required to understand the role of the oceans in climate change; this is view with which I strongly disagree.

The international perspective

Mills' review of the early history of biological oceanography (Mills 1989), including work up to the decade of the 1960s, concluded with the observation that the science in its formative years was driven largely by politics and economics (i.e. food from the sea). Later (post-World War II), national defense interests became prominent and the navies of the developed world began to invest significantly in oceanography (of which biological oceanography initially was a small component). This was matched and surpassed, starting in the 1970s, with what is referred to as "Big Science", i.e. multi-disciplinary ocean research projects of national or often international scope. Projects under the auspices of the International Decade of Ocean Exploration (IDOE) are a good example. In biological oceanography, as is the case with other ocean disciplines, this model has continued into the 21st century as the scientific questions being addressed have grown

in scope (e.g. climate change). Although it is true that individual or small team biological oceanographic inquiry is still thriving, many of the contemporary achievements considered of major significance have come about through the cooperative research of scientists working in large networks on broad-scale projects.

In the last few years, the Ocean Studies Board of the US National Science Foundation (NSF) commissioned a study of the landmark achievements in oceanography over the past 50 years. Professor Richard Barber, heading up the study on biological oceanography, summarized the discussions from the retreat sponsored to address this question and responses from some 150 practicing biological oceanographers (Barber & Hilting 2000). Barber indicates that prior to World War II (WWII), biological oceanography had two main themes: (1) locating and understanding causes of the variability in exploitable living marine resources (i.e. fisheries) and (2) curiosity-driven discovery, i.e. the search for strange and exotic organisms in the ocean. After WW II, biological oceanography became a growth industry with the infusion of significant new funds and substantial increases in universities teaching biological oceanography and the subsequent expanded pool of biological oceanography graduates entering the workforce. The balance between applied and basic research began to shift towards the latter and although effort continued in the areas of food from the ocean and new concerns about pollution, much more research was directed to discovery and knowledge for knowledge sake. Interestingly enough, the pre-war interest in collaboration between fisheries and ocean sciences lost much of its momentum in the new era, and progress in understanding the role of environment in fluctuations in living marine resource variability, recruitment and survival has progressed little in the intervening years.

Eight landmark achievements were identified in the NSF study. Four were related to new technologies for studying the ocean from within and from above. The first two were largely a consequence of the introduction of deep-sea submersibles, i.e. the discovery of much higher biological diversity in the deep-sea than had been believed up to that time and the discovery of previously unknown complex and unique chemosynthetic ecosystems residing in and around hydrothermal vents at sites of seafloor spreading. The 3rd was the remarkable research using innovative high-speed micro-cinematography aimed at understanding the intricate swimming, feeding and reproductive behavior of marine zooplankton. The 4th was the advent of earth resource-mapping sensors aboard orbiting satellites, namely the Coastal Zone Color Scanner (CZCS) launched in 1978 to map coastal resources. CZCS operated for almost 8 years and provided an unprecedented view of the scales of variability of ocean biota (phytoplankton chlorophyll). More precisely, CZCS provided insights into the realization of how inadequate conventional sea-going sampling (i.e. via ships) is for characterizing ocean variability and how mesoscale processes dominate the spatial patterns of distribution. Moreover, satellite ocean colour has

revealed clearly the complexity of seasonal phytoplankton cycles and the magnitude of interannual variability, properties that have been difficult to describe adequately heretofore. Canadian oceanographers are currently world leaders (and educators) in the R&D and application of satellite remote-sensing of ocean colour.

A 5th achievement, related somewhat to the advent of "satellite oceanography", but predating it, has been the application of isotopic tracer methodology (^{14}C & ^{15}N) in the 1950s and 1960s to the study of ocean primary production. The accumulation of productivity data world-wide over the past 50 years combined with spatially synoptic ocean colour primary-producer biomass fields have permitted realistic estimates of global marine primary production for the first time (Longhurst et al. 1995). Canadian biological oceanographers, Alan Longhurst and Trevor Platt, have extended these new observations to produce a scheme for partitioning the ocean into biogeochemical domains and provinces (Fig 4) based on phytoplankton growth dynamics and the underlying physical forcings (Longhurst 2001). In a similar way, isotope tracer studies of productivity based on the nitrogen nutrition of phytoplankton from the laboratories of Dugdale and Eppley formed the basis of the 6th achievement, a new conceptual framework differentiating "new" (or physically-mediated) from "regenerated" (or biologically-mediated) primary production (Dugdale & Goering 1967, Eppley 1981). The new and regenerated production model has provided an explanation for regional differences in primary production and the underlying physical-biological driving forces. In addition, it has provided a rationale for relating surface production to export of biogenic matter to the deep ocean (Eppley & Peterson 1979); a process that is critical for understanding the "biological carbon pump" and the role ocean biota play in the global carbon cycle and ultimately in climate

Fig 4 Biogeochemical domains and provinces of the global oceans (Longhurst 2001)

change. Canadian university and government biological oceanographers have been strong proponents of the new and regenerated production concept and have been actively involved in its application.

A 7th achievement was John Martin's elucidation of the "iron hypothesis" to explain the perplexing observation of vast areas of the contemporary oceans where surface nutrients are not effectively utilized by phytoplankton (Martin et al. 1994). Martin suggested that phytoplankton production is limited by the availability of atmospheric iron, an essential growth element, which is deficient in areas where surface nutrients are under-utilized. Similarly, he explained the large glacial-interglacial changes in atmospheric carbon dioxide in the geological record by the influence of iron availability on ancient productivity rates that, in turn, regulated atmospheric carbon dioxide concentrations. The Canadian biological oceanographic community has played a significant role in testing this hypothesis, through the Canadian JGOFS and more recent SOLAS programs' *in situ* Fe-fertilization experiments and ecosystem modelling (Boyd & Harrison 1999).

The 8th and last achievement, considered by the community of contributors to be the most far-reaching, is the characterization and recognition of the importance of the microbial components (viruses, bacteria, pico and nano-phytoplankton, micro-grazers) of the pelagic food web. The evolving picture of a complex community of interacting microorganisms that play a pivotal role in trophic energy transfer and ocean biogeochemistry has forced the biological oceanographic community to re-examine its traditional and simplistic view (phytoplankton-zooplankton-fish) of the structure and function of the ocean pelagic ecosystem. Canadian biological oceanographers played a pioneering role in the discovery of pico-phytoplankton (Li et al. 1983) and in establishing their role in productivity of the pelagic ecosystem; moreover, they are promoting the new concept of microbial "macro-ecology" (Parsons 2003) in explaining regional to global patterns in plankton distributions (Li 2002, Li et al. 2004) and microbial metabolism (Rivkin & Legendre 2001) in the ocean. Fig 5, for example, shows that the relationship between bacteria and phytoplankton at the global ocean scale is more complex than initially thought. The commonly held view of a positive bacteria-phytoplankton relationship (strong trophic coupling) holds for much of the phytoplankton concentration range. Under conditions where phytoplankton biomass is moderate to low (e.g. low latitude, continental shelf and open ocean waters), bacteria are regulated by substrate provided principally by primary productivity, i.e. "bottom-up" control processes dominate. Where phytoplankton concentrations are moderate to high (e.g. coastal, inshore, upwelling or high latitude waters), however, the bacteria-phytoplankton relationship plateaus or is negative, suggesting a fundamental trophic decoupling. Under these conditions, bacteria are more commonly regulated by bacterivory or viral attack i.e. "top-down" control processes dominate (Li et al. 2004).

Thus ocean macroecology is a means of studying the relationships between marine organisms and their environment at the largest scale (ocean basin to global) based on statistical characterization of emerging patterns

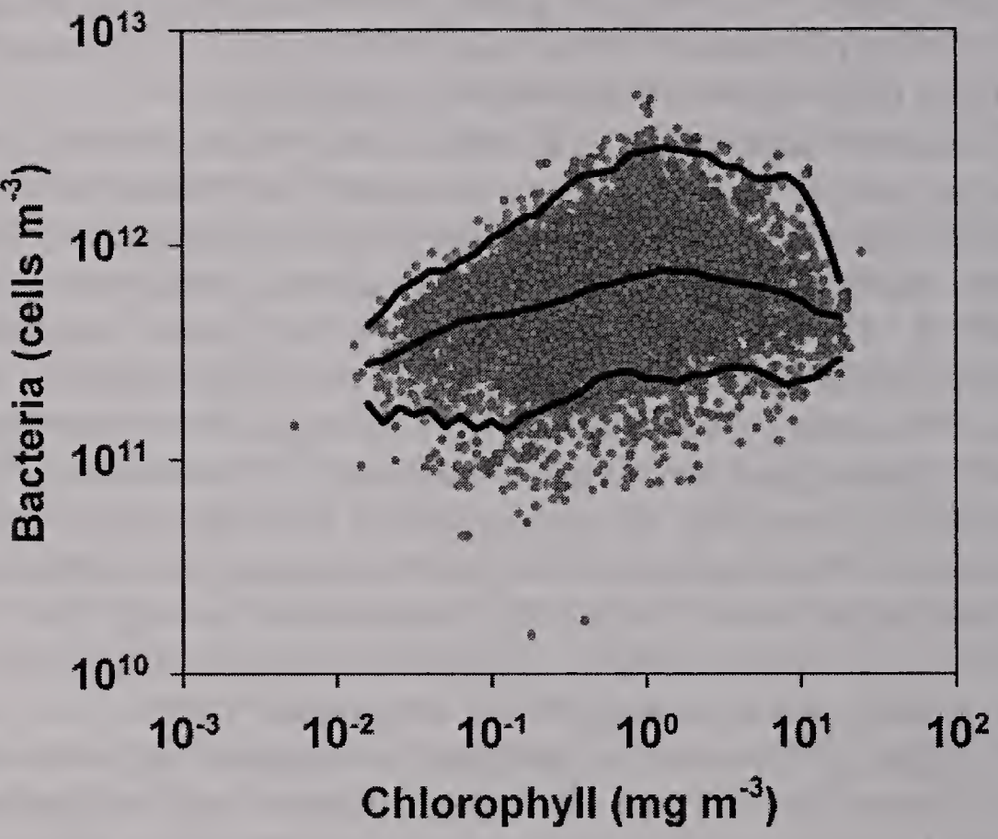

Fig 5 Macroecological analysis of the relationship between bacterial abundance and chlorophyll concentration (proxy of phytoplankton). Canadian and international JGOFS data archives from the subtropical and North Atlantic, equatorial and North Pacific, Arabian Sea, Arctic and Antarctic oceans. Statistical percentile lines are generated from bacterial distributions within successive binned (0.1 logarithmic units) chlorophyll intervals: the 50 percentile line (middle line), for example, defines the median bacterial abundance for a specified chlorophyll concentration; 5 (lower line) and 99 (upper line) percentiles essentially set the statistical bounds of the bacteria-chlorophyll relationship (Li et al. 2004). Note the positive bacteria-chlorophyll relation at chlorophyll concentrations $<10^0$ mg m^{-3}, suggesting strong trophic coupling and "bottom-up" control. At chlorophyll concentrations $>10^0$ mg m^{-3} the relationship is decoupled and bacteria are "top-down" controlled by bacterivory or viruses.

of abundance, distribution, community structure, etc. It can be considered an extension of comparative ecosystem analysis. This line of investigation in biological oceanography has benefited greatly from the proliferation of electronic databases of ocean observations, such as those that reside in the Canadian federal government's Marine Environmental Data Service (MEDS, http://www.meds-sdmm.dfo-mpo.gc.ca/meds/Home_e.htm) or other international data repositories (e.g. BODC, http://www.bodc.ac.uk/ and NODC, http://www.nodc.noaa.gov/).

THE FUTURE

Societal needs

Because of the ever-increasing cost and demands on public and private funding supporting oceanographic research, it is becoming a commonplace that a rationalization beyond mere curiosity is required. More often than not,

justification at the highest level may be sought and based on more practical public good concepts such as maintaining a national leadership role in technology development, "wealth creation", etc. This is becoming particularly true for the support of federal oceanographic laboratories (Canada being no exception) and in the justification for international research initiatives.

Again, the Ocean Sciences Board of the US National Science Foundation (NSF), reporting on their vision of oceanography in the next decade, attempted to identify the major societal issues that will drive ocean science in the early 21st century. At the international level, the Partnership for Observation of the Global Oceans (POGO) recently produced a report on the requirements for biological oceanographic observations of the global ocean and how to meet them (http://ocean-partners.org/documents/Dartington_Report.pdf). In that report, a list of societal needs was generated that was similar to the list produced by the NSF Ocean Sciences Board. Among the most pressing issues identified were: (1) sustainable development (and management) of living marine resources and the allied issues of (2) conservation and maintenance of biodiversity and (3) habitat protection; (4) environmental quality, (5) bio-invasions, and finally (6) global (climate) change. The oceans are the largest "global commons" and Canada, as one of the "G-8" and a major maritime nation, must contribute to the stewardship of global marine resources. Furthermore, DFO has a leading role in ocean research to meet this obligation for the public good.

Each of these issues to some degree is of relevance to and should be of concern to Canadians. Government and university biological oceanographers have an important role to play in monitoring the marine environment and its resources, detecting (and predicting) change and providing advice (technical options) for managers and policy makers. Specifically, Canadian government science (DFO) has the prime responsibility for ocean resources management, conservation and habitat protection. The Canada Oceans Act, and the responsibilities it confers for the stewardship of the oceans off Canada, and DFO's commitment to an 'ecosystem approach' to resource management means that the need for biological oceanographic expertise has never been greater.

Scientific problems 20th and early 21st century science has not yet solved

Strategic planning on future needs for ocean sciences has been the subject of a number of discussion papers internationally in recent years. Similar scoping meetings among government and university ocean scientists encompassing the needs of Canadians in the broadest sense have not occurred yet. DFO has begun discussions on the scientific expertise it will need in the coming years, but to date the scope of these deliberations has been restricted to a relatively narrow mandate as perceived by senior managers. For the purposes of this review, therefore, I will draw on the unanswered questions posed by the international community as a guide to what Canada's future for biological oceanographic research might look

like. Two discussion papers of particular interest are my principal sources; the Ocean Ecology: Understanding and Visions for Research (OEUVRE) workshop report sponsored by the Ocean Sciences Board of the US National Science Foundation (http://www.ofps.ucar.edu/joss_psg/project/oce_workshop/oeuvre/report/Entire.pdf) and the International Geosphere-Biosphere Program / Scientific Committee on Oceanic Research (IGBP/SCOR) joint report on future research requirements in ocean biogeochemistry (http://www.igbp.kva.se/obe/FW-Final-2002.pdf). The latter report addresses principally issues concerned with climate change research while the former is much broader and embraces the more complete suite of societal issues posed previously.

The premise for the OEUVRE report on the future of biological oceanography is that "Humans have fundamentally affected marine ecosystems worldwide via fisheries, aquaculture, introductions of non-native species, modification or destruction of crucial habitats, and the additions of nutrients and chemical pollutants. No part of the ocean remains unaffected. Human population increases are affecting coastal oceans more profoundly and more rapidly than global climate change, producing an urgent need to understand, predict and mitigate these changes. Ocean ecology can no longer be understood adequately without recognizing these ecosystem-wide perturbations." The report goes on to indicate that the "grand challenge" is to act with incomplete knowledge and build our understanding through learning by doing. Among the greatest challenges ahead will be separating the "signal from the noise", i.e. understanding and differentiating anthropogenic effects from natural variability. Critical issues and opportunities raised in the report include:

- Ocean ecologists (biological oceanographers) must promote better stewardship of marine ecosystems by understanding and predicting perturbations and food-web alterations and by providing mitigative options.
- To meet these challenges, better understanding of causes and consequences of ecosystem change on small to large scales will be required. Sorting out these changes will, among other things, require extensive time-series of ocean observations, exploiting traditional as well as new observational technologies (molecular probes through to global scale remote-sensing).
- Prediction will require better understanding of the basic rules of ecology affecting community structure and function. Mitigation will require the application of this understanding by manipulation in some way of critical components of ecosystems (species, their interactions) that can be used to return the ecosystem to the desired state.
- Marine reserves (or Marine Protected Areas) will become valued tools in the coming decades for ecosystem preservation, recovery and for intentional manipulation for development of more effective ecosystem management strategies.

- Understanding gained from the above can then be applied to forecast ecosystem change resulting from natural and anthropogenic effects, and assess the extent to which mitigative (restorative) actions are possible and offer options.

The nature and complexity of these important questions imply that a substantial (perhaps unprecedented) commitment of planning and resources (human and otherwise) will be required if they are to be addressed. They also imply the need for strong collaboration between university and government scientists (national and international). Biological oceanographers within Canadian universities and federal government departments (specifically DFO) are up to the challenge and have demonstrated through participation in major national and international research initiatives the capabilities needed for tackling complex scientific problems through cooperation and resource sharing (e.g. Canada's participation in JGOFS, GLOBEC, NOW, SOLAS, CASES and leadership role in new international initiatives such as IMBER). Participation of both sectors will be required since the issues include not only the science (responsibility of both academia and government) but the mitigative options that have traditionally been the purview of government.

My personal concern is that the contribution of government to the science and maintenance of its expertise in the oceanographic disciplines is increasingly being viewed as a responsibility of academia. Most academic research, however, generally has a relatively short life cycle of a few years, e.g. the SOLAS project. Societal issues of concern, on the other hand, require a much longer period of sustained study, which is better suited to government science. Compromising science capacity in the government in light of the legal responsibilities and challenges for ecosystem understanding embodied in Canada's Ocean's Act and climate issues articulated in the Intergovernmental Panel on Climate Change (IPCC) documents and Kyoto Protocols (http://www.ipcc.ch, http://unfccc.int/resource/docs/convkp/kpeng.pdf) seems short-sighted. More than ever, decisions within the government based on good science, backed up by a cadre of world-class government scientists (including biological oceanographers), will be essential. Canada, among all the developed nations, has been notable in the global science community in its strong representation by government scientists – this tradition has worked well in the past for Canada and should be continued.

The IGBP/SCOR report, addressing the way ahead for ocean biogeochemistry (and the framework for the new IMBER project), is structured around three major issues: (1) what controls the time-varying biogeochemical state of the ocean and how will it respond to global change? (2) how will the marine food webs respond to, and force, global change? and (3) how does carbon accumulation in the ocean, as well as the release of carbon dioxide and methane, respond to global change? Among these issues, a number of subsidiary questions are of particular relevance to future research in biological oceanography:

Issue 1:

- What role will the mesopelagic layer (100-1,000 m depths) play in global change?

Issue 2:

- What are the relations between elemental cycling and food web structure?
- What are the roles of physical and chemical drivers in determining marine food web structures and functioning?
- What are the relations among biodiversity, structure, function, and stability of marine ecosystems?
- How do variations in marine food webs manifest themselves over various time and space scales?

Issue 3:

- What is the effect of climate variability on the ocean's biological pump (i.e. carbon sequestration in the deep ocean mediated by ocean biota)?

Without exception, the questions posed above are of relevance to Canada. Moreover, as mentioned previously, Canadian ocean scientists (academia and government) have taken leading roles internationally in planning and executing research on the biogeochemistry of the oceans, particularly with regard to climate change issues, and continue to contribute to the identification of the pressing problems for the future. Sustaining this momentum within Canada is clearly in the best interests of the country since climate change will be a reality for Canada; because of its geography, climate change manifestations may be more dramatic and may reach our shores well before it reaches those of our global neighbours.

In concluding the discussion of future needs in biological oceanography, I must comment on radically new technological advances in genomics (the science of mapping the genetic code of organisms and research on the implications of this molecular-level knowledge), not envisioned when Parsons wrote his review in the mid-1970s. An explosive growth of research on mapping the genetic code of marine plankton is underway. Recently, it was announced that the genetic blueprints for four closely related microorganisms in the ocean plankton (three strains of the unicellular cyanobacteria Prochlorococcus and Synechococcus) have been sequenced (Fuhrman 2003). These organisms are ubiquitous and constitute the smallest in individual size, but are the most abundant photosynthetic microorganisms in the world's oceans. In fact, contemporary communities of bacteria and protists are believed to account for up to 98% of the ocean's living biomass and have a much greater influence on the global biogeochemical cycles of the oceans than previously thought. It is anticipated that breaking the genetic code of these micro-organisms will lead to new understanding, not otherwise possible, at the organism level (e.g. photosynthetic physiology),

community level (biodiversity) and up to the global scale where genetic research may provide new insights into the role of phytoplankton and bacteria in the ocean carbon cycle and climate change. Indeed, a new sub-discipline of biological oceanography, termed "Microbial Oceanography", has emerged as an umbrella for these new and traditional microbial studies. Efforts are well under way, for example, under the auspices of the Census for Marine Life initiative (COML, http://www.coreocean.org/Dev2Go.web?Anchor=coml_home_page&rnd=15141) to develop a roadmap (scope, knowledge gaps, methodologies, coordination and education) for future research in this new field. Currently, there are more than 1,000 genome-sequencing projects around the world. These include work on marine phytoplankton (diatoms, dinoflagellates, coccolithophores, cryptomonads, prasinophytes, prymnesiophytes), on marine bacterioplankton (cyanobacteria, proteobacteria), on marine zooplankton (appendicularian), and even on marine meroplankton species (lobster, crab, shrimp). As far as I am aware, Canadian government oceanographers are not involved in any of these projects. In modern medical research, molecular biology is already the common foundation across all sub-disciplines. There are some that draw an analogy between the health of human beings and the health of marine ecosystems; clearly, molecular biology will be an important part of the foundation of biological oceanography in the future.

An interesting fall-out from this new genetics research, as well as research into the influence of plankton community structure on ocean biogeochemistry (IMBER), is a resurgence of interest in taxonomy and systematics; disciplines that were synonymous with biological oceanography in its infancy. Experts in phenotypic classification of plankton communities are a dying breed within Canada as well as globally despite the growing need for this expertise. The problem is confounded by the fact that universities (with few exceptions) do not train oceanography students in taxonomy. More importantly, the population of scientists with even a basic knowledge of systematics is rapidly disappearing. This must be rectified. The new discipline of chemical taxonomy (including genetics) still needs the benchmark of simple microscopic analysis!

CONCLUDING REMARKS
WHERE DO WE STAND AND WHERE DO WE GO?

Canadian biological oceanography has a rich history pre-dating the formal beginning of marine scientific research in the country with the establishment of the St Andrews and Nanaimo field stations in the early 1900s. Canadian biological oceanographers over the years have distinguished themselves by being leaders in the early developments of the discipline, including methodologies, concepts and understanding of both pelagic and benthic ecosystems. In more recent years, Canadian biological oceanographers have led in the conceptualization, planning and implementation of major

interdisciplinary/international research initiatives on climate change and ecosystem dynamics and are making important contributions to research aimed at understanding the influence of ecosystems on harvestable living resource variability and conservation. Clearly, Canadian biological oceanographers have made (and continue to make) significant contributions to the understanding of the biology of the oceans and its interactions with the physical, chemical and geological world.

Present strengths in biological oceanographic research in the Canadian government fall under three broad categories: ecosystem and climate monitoring, ecosystem and climate process studies, and modelling. With regard to monitoring, the Atlantic Zone Monitoring Program (AZMP) was established by DFO principally to provide more comprehensive and systematic long-term observations of the oceanographic and foodweb properties of the NW Atlantic in support of resource management and to improve understanding of the relationships between harvestable resources and their environment – much as Tim Parsons envisaged. AZMP and other DFO monitoring activities (e.g. ecosystem trawl surveys) have proven to be of much broader significance and are playing a important role in the development, internationally, of a global network of ecosystem observations through the Global Ocean Observing System (GOOS), for example (http://ioc.unesco.org/goos/). In a like manner, climate system monitoring, (e.g. biogenic carbon inventories and transport) in the Labrador Sea in the Atlantic and OWS "PAPA" in the Pacific are making valuable contributions to the international research community seeking an understanding of the effects of climate change on ocean biota and biotic feedbacks through the ocean carbon cycle. It is also noteworthy that DFO biological oceanographers are among the world leaders in the development and application of satellite (ocean colour) remote sensing for monitoring and research. With regard to process studies, DFO biological oceanographers distinguish themselves in areas of distribution, production, physiology and trophic interactions among the plankton and microbial components of the foodweb as they relate both to ecosystem structure/function and to climate feedbacks. DFO biological oceanographers also have particular strengths in ecosystem model development and application. Noteworthy among these, for example, are inverse models (Vézina et al. 2004), data assimilation, "adaptive" optimization approaches for modelling biogeochemical interactions (Pahlow & Vezina 2003) and parameterization of ecosystem models for integration into global climate models (Denman 2003). Sustaining Canada's strengths in biological oceanographic research, especially within federal government laboratories, will be a considerable challenge, however, if trends of shrinking resources and low recruitment persist.

Despite these strengths, there are areas in which DFO's biological oceanographic community (and oceanographers of other disciplines as well) should place more emphasis. While systematic, comprehensive, and high-quality ecosystem data collection, cataloguing and basic reporting is a major focus

of effort in the Department at present, data integration and interpretation are lagging (see Parsons 2002). DFO also leads in the exploitation of new technologies (e.g. satellite remote sensing), however, the integration of these data with conventional observations and assimilation into dynamical models needs more effort, i.e. biological oceanography needs to move towards an "operational oceanography" mode (Parsons 2002). Finally, serious consideration needs to be given to the role DFO wants to play in the emergent field of "microbial oceanography" and genomics applications in biological oceanography. At present, DFO has limited capacity and little potential for growth in this area without significant investment. This is a true revolution in science and the time is at hand to decide if Canadian government oceanographers are going to be players or sit on the sidelines. It would be a shame indeed if DFO oceanographers were relegated to a role of handmaidens to foreign researchers who sail into Canadian waters seeking only jurisdictional assistance for their marine genome projects. The challenge of sequencing the human genome has been met and attention is now being turned to sequencing the metagenome of plankton in the ocean (Venter et al. 2004).

The challenge of solving the complex scientific and societal problems facing us now and in the future, however, will require better planning, coordination and stronger commitment to the ocean sciences by both universities and government. The government science departments, in particular, are losing critical expertise, infrastructure and capacity when the need is greatest. Without a substantial reinvestment in people, core funding and ships, the federal government's biological oceanographic research capacity (and oceanographic capacity in general) cannot be sustained. As a consequence, the department's prestige and credibility will be diminished, opportunities for collaboration and synergy will decrease and, most importantly, the department's capability to solve many of the ecological problems within its mandate will be compromised. A strong national voice for oceanography and serious strategic planning for the future to define goals and responsibilities is urgently needed and should include not only government and universities, but also industry and the private sector.

On the occasion of the 40th anniversary of DFO's Bedford Institute of Oceanography in 2002 (Geddes et al. 2003), a number of scientific leaders in the physical, chemical, geological and biological disciplines of oceanography were invited to participate in the celebration and provide their views on the progress that has been made in their respective field over the past several decades and to speculate on its future. Professor Paul Falkowski of Rutgers University gave a compelling yet provocative talk on the past and future of biological oceanography, entitled, "Putting the Biology back into Biological Oceanography". Rather than providing a detailed history of accomplishments in the field, his presentation highlighted some of the remarkable biological oceanographic discoveries made in very recent years and showed their relevance to the understanding of some of the most fun-

damental questions in science, such as the evolution of life on earth and the role of ocean biology in the planetary cycles of the major biogeochemical elements. He suggested, however, that biological oceanography is "on the cusp of either becoming irrelevant or making a major contribution to understanding planetary processes". He then explained his reasoning by emphasizing how much biological oceanography has to offer the other traditional ocean disciplines (physics, chemistry and geology) and the new disciplines of molecular biology and genomics and stressed the need for integration of disciplines to tackle the big questions, a number of which I described previously. Biological oceanography, in his words, is in search of context.

I am certain that Canadian biological oceanographers have a sense of their context and are now and will continue to forge alliances with physical, chemical and geological oceanographers (and new disciplines) to tackle the pressing scientific and societal problems, some of which have been highlighted above. In reality, the role Canada's oceanographers play as participants with the global science community in meeting these ambitious goals is what is presently "on the cusp". What will be required is a renewed commitment to and recognition that strong national support for oceanography is in Canada's best interest, is a good investment and is both a government and university responsibility.

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GLOSSARY AND WEB-LINKS

ArcticNet – ArcticNet, Network of Centres of Excellence of Canada (http://www.arcticnet-ulaval.ca)

AZMP - Atlantic Zone Monitoring Program

BIO – Bedford Institute of Oceanography

BODC – British Oceanographic Data Centre (http://www.bodc.ac.uk/)

CASES - Canadian Arctic Shelf Exchange Study (http://www.cases.quebec-ocean.ulaval.ca/index.html)

CCGS Amundsen – Canadian Research Icebreaker (http://www.amundsen.quebec-ocean.ulaval.ca)

CMB – Centre for Marine Biodiversity (http://www.marinebiodiversity.ca/en/corridor.html)

COML – Census of Marine Life (http://www.coreocean.org/Dev2Go.web?Anchor=coml_home_page&rnd=15141)

DFO – Department of Fisheries and Oceans

EC – Environment Canada

EBFM – Ecosystem-based fisheries management

ECOPATH – (http://www.ecopath.org/)

ESSAS – Ecosystem Studies of Sub-Arctic Seas – (http://www.pml.ac.uk/globec/structure/regional/essas/essas.htm)

GFC – Gulf Fisheries Centre

GLOBEC - Global Ocean Ecosystem Dynamics (http://www.pml.ac.uk/globec/main.htm)

GOOS - Global Ocean Observing System (http://ioc.unesco.org/goos/)

ICES – International Council for the Exploration of the Sea

IDOE – International Decade of Ocean Exploration

IGBP/SCOR – International Geosphere-Biosphere Programme / Scientific Committee on Oceanic Research. Draft framework for future research on biological and chemical aspects of global change in the ocean (http://www.igbp.kva.se/obe/FW-Final-2002.pdf)

IMBER - Integrated Marine Biogeochemistry and Ecosystem Research. Draft Science Plan and Implementation Strategy (http://www.igbp.kva.se/obe/IMBERSP-IS-15Jan04.pdf)

IOS – Institute of Ocean Sciences

IPCC – Intergovernmental Panel on Climate Change (http://www.ipcc.ch)

IPY – International Polar Year Canada (http:/www.ipy-api.ca)

JGOFS – Joint Global Ocean Flux Study (http://www.uib.no/jgofs/jgofs.html)

Kyoto Protocol – (http://unfccc.int/resource/docs/convkp/kpeng.pdf)

Lunenburg Bay Project – Interdisciplinary Marine Environmental Prediction in the Atlantic Coastal Region (www.cmep.ca/bay)

MEDS – Marine Environmental Data Service (http://www.meds-sdmm.dfo-mpo.gc.ca/meds/Home_e.htm)

MLI – Maurice-Lamontagne Institute

MPA – Marine Protected Area

NEPTUNE – North-east Pacific Time-series Undersea Networked Experiments (http://www.neptunecanada.ca)

NODC – National Oceanographic Data Center (http://www.nodc.noaa.gov/)

NOW - International North Water Polynya Study (http://www.fsg.ulaval.ca/giroq/now/wel.htm)

NRCan – Natural Resources Canada

NSF – National Science Foundation

NWAFC – Northwest Atlantic Fisheries Centre

OEUVRE - Ocean Ecology: Understanding and Vision for Research (http://www.ofps.ucar.edu/joss_psg/project/oce_workshop/oeuvre/report/Entire.pdf)

OWS – Ocean weather station

PBS – Pacific Biological Station

POGO - Partnership for Observation of the Global Oceans. Biological observations of the global ocean: requirements and how to meet them (http://ocean-partners.org/documents/Dartington_Report.pdf)

Polynya – An area of open water in high latitude oceans surrounded by sea ice, often referred to as “north water”

SABS – St Andrew’s Biological Station

SEAMAP – Seabed Resource Mapping Program (http://seamap.bio.ns.ca/)

SOLAS – Surface Ocean – Lower Atmosphere Study (http://www.uea.ac.uk/env/solas/)

UBC – University of British Columbia

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A HISTORY OF MARINE FISHERIES SCIENCE IN ATLANTIC CANADA AND ITS ROLE IN THE MANAGEMENT OF FISHERIES

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The roots of fisheries science on the Atlantic coast of Canada go back to 1898. The primary research agencies were the Fisheries Research Board of Canada and predecessors until the early 1970s and subsequently the federal department responsible for fisheries. Canadian research on Atlantic fisheries expanded substantially after the Second World War, at about the time the International Commission for the Northwest Atlantic Fisheries was formed, and increased again after the 1977 extension of fisheries jurisdiction, but gradually declined from the 1980s. Initially research was directed at improving and expanding the fisheries through exploring for new resources and by introducing and testing new fishing methods and new processing technologies, but increasingly was directed towards rational exploitation of the fisheries as international fishing effort greatly expanded in the 1960s. By the 1980s, the provision of short-term advice on catch limits occupied a large proportion of science resources. This paper describes these changes with primary reference to groundfish fisheries, which were the most important for much of the period.

Les racines des sciences halieutiques sur la côte atlantique du Canada remontent à 1898. Jusqu'au début des années 1970, les principaux organismes de recherche étaient le Conseil de recherche sur les pêcheries du Canada et ses prédécesseurs. Par la suite, le ministère fédéral responsable des pêches a assumé ce rôle. La recherche menée au Canada sur les pêches dans l'Atlantique a pris beaucoup d'ampleur après la Seconde Guerre mondiale, à peu près au moment où la Commission internationale pour les pêcheries de l'Atlantique Nord-Ouest a été créée, et également après l'élargissement du champ de compétence du Canada en matière de pêche en 1977, mais elle est en période de déclin graduel depuis les années 1980. Au début, la recherche était axée sur l'amélioration et l'expansion des pêches par le biais de l'étude de nouvelles ressources et de l'élaboration et de l'essai de nouvelles méthodes de pêche et technologies de transformation. Au fil du temps, le point de mire de la recherche est devenu l'exploitation rationnelle des ressources halieutiques, étant donné l'important accroissement de l'effort de pêche sur la scène internationale dans les années 1960. Dans les années 1980, une bonne part des ressources scientifiques étaient occupées à fournir des conseils à court terme à propos des limites de prises. Le présent document décrit ces changements en mettant l'accent sur les pêches de poissons de fond, qui étaient les activités les plus importantes pour la majeure partie de cette période.

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INTRODUCTION

This paper provides a brief description of the development of fisheries science in Atlantic Canada in the context of the evolution of the marine fisheries and their management in the Northwest Atlantic. Emphasis is placed on groundfish (benthic species such as Atlantic cod, haddock, redfish and flatfish) as historically they have been of most importance to the fishery, even if no longer so. The foundations of modern fisheries science were laid in the first half of the 20th century (Smith 1994) but the focus of this paper is primarily on the period from 1950, i.e. from the time when international institutions were put in place to apply fisheries science broadly to North Atlantic fisheries (Halliday & Pinhorn 1996). References to 'management' in accounts of the fisheries prior to this date relate almost exclusively to maintenance of order on the fishing grounds and to the over-riding question of "who gets the fish?" (Gough 1991, 1993).

Fisheries science is science that is conducted in support of the management of fisheries. Its central element is biological research on the factors controlling the production of aquatic species of possible or established commercial importance and estimation of their yield potential. However, it is usually viewed more broadly to include monitoring of fishing activities, of fish populations and of the environment, and research on fishing gears and practices and on the effects of fishing on the environment. It includes also research on the economic and social aspects of the fishing industry, and technological and product research and development.

In contrast, fisheries management is the administration of fishing-related activities to provide whatever societal benefits that the management authority considers worthwhile. A pre-condition to managerial success is preventing fishing from reducing the productive capacity of the resource. Thus, the key role of science is to define the biological bounds within which the social and economic benefits from fishing can be pursued. However, science has also been used to define 'optimal' exploitation strategies in terms of tonnage caught, catch per unit of fishing effort, and size or condition of the fish caught.

The success of fisheries science depends not only on the amount of new knowledge and information it generates, but also on how effectively this knowledge is communicated to fisheries managers and to the fishing industry. Thus, the institutional arrangements for the transformation of knowledge into practical advice are described also. It is equally the case, however, that the science contribution to management is devalued if it is not properly utilized or if the management authority does not establish effective control of fishing activities. Thus, institutional arrangements for management also have a place in this review.

THE FISHERIES

There are a number of descriptions of the marine fisheries in the Northwest Atlantic from their beginning in the early 1500s to the present day, the most recent being that by Lear (1998). By the early 1900s, the fishing banks off Canada's coast were exploited by local fleets from Canada, Newfoundland and the United States, and by the salt-cod fleets of France and Portugal. However, the introduction of the factory-equipped freezer stern trawler in 1954 revolutionized the fishery in the Northwest Atlantic, and throughout the world. These vessels combined the concepts of stern trawling with on-board filleting machinery, freezing capability and a fish-meal reduction plant and thus removed the constraint placed on distant-water fishing by the limited time fish can be preserved on ice. Development of one-boat mid-water trawling in the late 1960s rounded out the capabilities of the factory trawler by greatly increasing its efficiency to catch pelagic species such as herring, mackerel, and capelin. These and other technological improvements that became widely available after the Second World War, such as synthetic twines, sonic fish location systems (echo sounder, Sonar) and radio-based navigational systems (Decca, Loran, Radar), opened the way for development of diversified high-volume fisheries and a consequent doubling of Northwest Atlantic catches in the 1960s.

The new, factory-trawler equipped, distant-water fleets that appeared in the Northwest Atlantic in the late 1950s initially competed directly with traditional participants in fisheries for cod, redfish, haddock, and flatfish, but also developed fisheries for new species. Particularly significant was the expansion of small-mesh gear fisheries, spearheaded by the Union of Soviet Socialist Republics (USSR) in the early 1960s, predominantly for red and silver hakes in the southern part of the area. The USSR also pioneered development of offshore Atlantic herring fisheries in the 1960s that, combined with Canadian development of large coastal herring fisheries to support a fish-meal industry, gave herring an increased prominence in Northwest Atlantic fisheries. Groundfish catches declined from the mid-1960s, but pelagic species catches increased, first for herring, then mackerel and capelin, so that catches overall were maintained until the mid 1970s. Invertebrate fisheries also assumed more importance through the 1970s, squids being of primary importance in an international fishery context. Despite these continuing diversions to new species, total catches reported from the Northwest Atlantic peaked in 1968 at 4.5 million tons (Fig 1). There was a subsequent decline in removals in the 1970s, followed by a period of stability in the 1980s at about 3.0 million tons and then a further decline in the early 1990s. Late 1990s removals were about 2.0 million tons, about the same as in the mid 1950s. Species composition was quite different, however, cod representing 50% of the catches in the mid 1950s, but only about 2% in the late 1990s (Fig 2). It was invertebrate species, lobster, scallop, shrimp, crab, etc., that represented 50% of the catch in the late 1990s (in terms of weight, and a substantially higher percentage in terms of value).

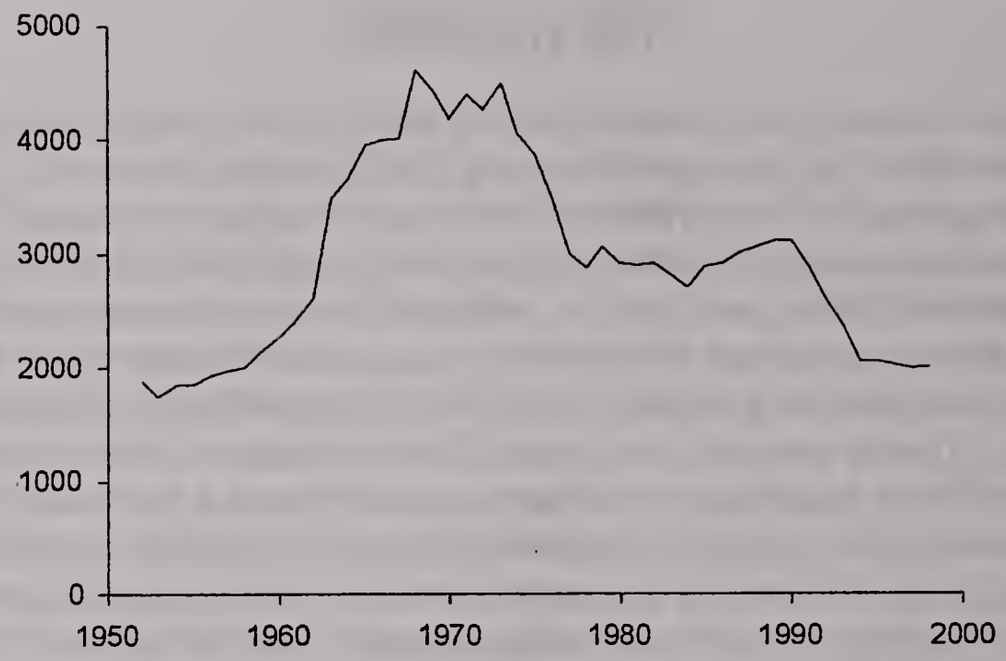

Fig 1 Reported catches from the Northwest Atlantic (all waters) in thousands of metric tons.

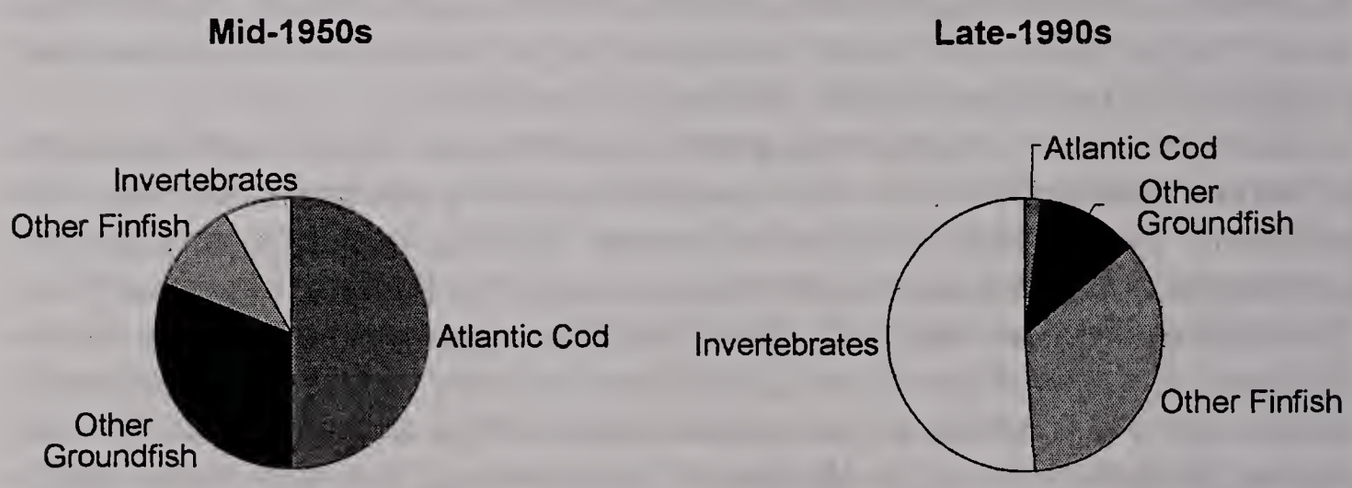

Fig 2 Proportion of catches from the Northwest Atlantic (all waters) by species group, late 1990s compared to mid-1950s.

FISHERIES MANAGEMENT

Until the late 1970s, fisheries were prosecuted, in large part, on the high seas and regulatory actions required international agreement. It was to this end that the International Commission for the Northwest Atlantic Fisheries (ICNAF) was established in 1950 "for the investigation, protection and conservation of the fisheries". Discussions at the Third United Nations Conference on the Law of the Sea reached a stage by 1976 that countries felt they were in a position to declare 200-mile fisheries zones. Canada extended its jurisdiction over most of the fishing banks off its coast (Fig 3) at the beginning of 1977. (Neighbouring states also extended their jurisdictions at about the same time.) However, important fishing areas on the eastern

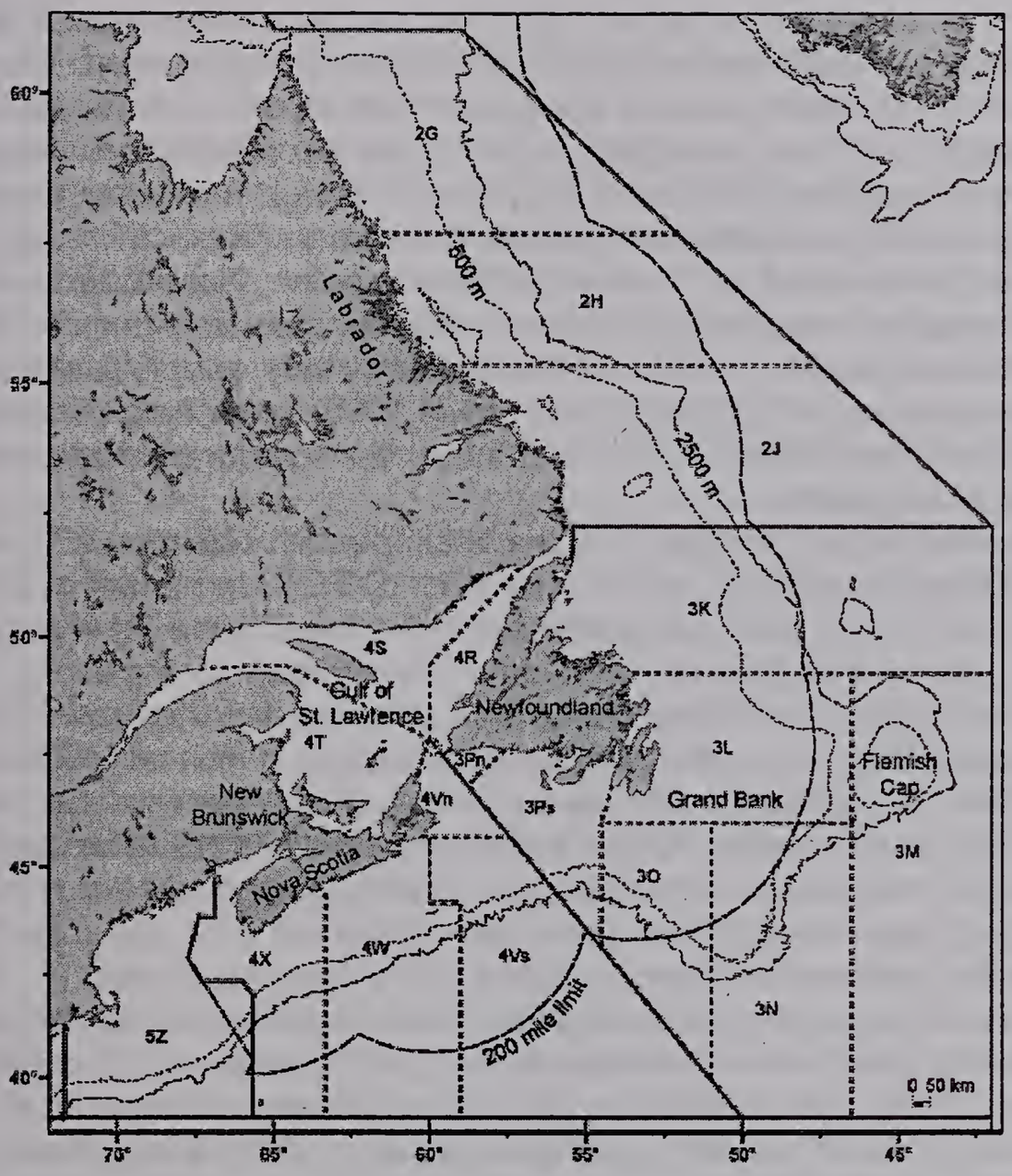

Fig 3 The Canadian fishing zone and the NAFO statistical divisions in Subareas 2-4.

and southern parts (nose and tail) of the Grand Bank, and on Flemish Cap, lay outside the new limits and thus there was a need for continuation of arrangements for international fisheries management in these areas. A new international convention came into effect in 1979, creating the Northwest Atlantic Fisheries Organization (NAFO), to meet this need.

A detailed account of the objectives, strategies and regulatory actions adopted by Northwest Atlantic management agencies, international and national, are provided by Anderson (1998), Halliday and Pinhorn (1996) and Parsons (1993a). The latter two publications provide comparisons among management programs on both sides of the Atlantic. Briefly, the objective of ICNAF was to prevent over-exploitation, by limiting fishing to the amount that provided for the maximum sustainable catch (yield) (MSY). However, MSY is an abstract concept not well suited to practical application (Gulland 1968, Larkin 1977), and ICNAF used as a proxy the maximum yield per recruit (see below). The primary strategies were to control a) the size at which fish were first captured by regulating the characteristics of fishing gears, particularly the mesh size in otter trawls, and b) the overall

mortality on those fish large enough to be caught, mainly by setting limits on the total allowable catch (TAC) that could be taken from each fish stock. The fishing mortality measure most commonly used is the instantaneous rate, designated by F, which theoretically is proportional to fishing effort, and that associated with maximum yield per recruit is referred to as F_{max}. Although ICNAF modified its objective to "optimal utilization" in 1971, F_{max} continued to be used as its target reference point. Nonetheless, ICNAF was a leader among international commissions in establishing catch limits for individual stocks in 1970 and in subsequently adopting second-tier constraints on catch (ICNAF 1974, O'Boyle 1985) and fishing effort (ICNAF 1976) to address fishery and species interactions and the limitations of the first-tier TAC system.

After extension of jurisdiction, Canada adopted an objective of "best use" to be defined in terms of net social benefits (DOE [Department of Environment] 1976). This was to be achieved by fishing at a low fishing mortality rate, $F_{0.1}$ (an F that gives a catch almost as high as fishing at F_{max} but at about two thirds of the fishing effort – for a technical definition see Gulland & Boerema (1973)). Canada had been successful in convincing ICNAF, in its dying days, to conform to this low F strategy. This consensus carried over into NAFO (which retained ICNAF's objective of optimal utilization) but broke down in the mid 1980s as the European Union, struggling to accommodate the fishing interests of its new members, Spain and Portugal, came to see F_{max} as the preferable reference point for NAFO management.

In Canada, legislative authority for fisheries lies with the federal government, which administers marine fisheries through its Department of Fisheries and Oceans (DFO)[1]. The bureaucracy in DFO, after consultations with scientific and fishing industry advisors, provides recommendations on policies, plans and regulations to the Minister, who carries the overall decision-making authority. Exceptionally, from 1993, an independent Fisheries Resource Conservation Council (FRCC) has provided recommendations directly to the Minister on conservation measures for groundfish stocks.

The Canadian fisheries bureaucracy is highly regionalized. On the Atlantic coast, there are Newfoundland, Laurentian and Maritimes regions, the last having two sectors the Gulf (southwestern part of the Gulf of St. Lawrence) and Scotia-Fundy. Each has administrative branches for managing the fisheries within their region, including policy, planning, licensing, surveillance and enforcement functions (referred to as operational branches or, collectively, as 'operations'), and a science branch. Most of the fisheries science conducted in Newfoundland Region pertains to fisheries in NAFO Subareas 2 and 3 (Fig 3), in Laurentian Region in Divisions 4RS and T (in part), Gulf Sector in Division 4T (in part) and Scotia-Fundy Sector in Divisions 4VWX and Subarea 5, but responsibilities for highly migratory species are assigned to particular laboratories on a practical basis.

[1] The name of the federal department responsible for fisheries has changed a number of times over the years and a generic designation as the 'fisheries department' is used in the remainder of the text to avoid confusion.

Canada's extension of jurisdiction in 1977 required the introduction of annual management plans, initially for groundfish, to establish TACs, allocate fishing opportunities between offshore and inshore fleets and to stretch out the resources to keep the industry operating year-round. Limited entry licensing and vessel replacement restrictions, intended to balance fleet catching capacity with resource availability, were introduced at this time. However, these measures proved ineffective and fleets expanded, causing demands for more fish and widespread underreporting and misreporting of catches (Halliday et al. 1992, Parsons 1993a). Management plans became progressively more complex as managers attempted to reconcile the catch aspirations of rival groups within inshore and offshore components with TAC limits. Development of fleet over-capacity is the classic consequence of fishing under a common property system because, under this system, fishermen see themselves as being in a race for the fish and are motivated to invest in ever bigger boats to compete (Gordon 1954). By the late 1970s, economists began to propose giving quantitative (property) rights to fishing entities (individual fishermen, fishing enterprises or communities) as a way to solve this problem. They argued that if fishermen were assured of being able to catch a certain amount of fish, they would no longer be motivated to increase their catching capacity. The effectiveness of this tool depends on many aspects of its application, particularly on the extent to which the rights are true property rights that can be freely bought and sold and, as for all catch limitation schemes, on the probability of violations being detected (Copes 1986). Reservations about the introduction of property rights are primarily about the potential for adverse social effects on individual fishermen and on coastal communities when the distribution of benefits from the fishery is at the mercy of market forces (Copes 1997). The introduction of such property rights to Atlantic coast fisheries began with the Bay of Fundy herring purse seine fishery in 1976 and in the offshore groundfish fishery from 1982 (Parsons 1993a) and subsequently to various other fisheries as the need arose.

For many years, the approach to management was fragmented; management plans were essentially catch sharing arrangements while regulations and policies were promulgated separately and insufficient attention was paid to measuring their effects. As a result, objectives were not being met (e.g., Angel et al. 1994). The introduction of "integrated" planning in 1995, which required inclusion of a statement of objectives and criteria for performance evaluation in management plans, was recognition of the need for a more focussed, cohesive approach. A major revision of the process begun in 2000, labelled the Objective-Based Fisheries Management (OBFM) planning initiative, addressed a number of outstanding weaknesses in implementation by adding a requirement for rigorous risk analyses and introduced the precautionary approach (FAO, 1995). Introduction of this comprehensive framework for the management of individual fisheries coincided with the promulgation of a new fisheries policy (DFO 2004), the first comprehensive

statement of policy since 1976 (DOE 1976)[2]. The objective of this new policy, in addition to conservation, is a self-reliant industry achieved through shared stewardship with stability and transparency in access and allocation. The value of the new policy and planning procedures is, of course, contingent on them being successfully implemented. An unacknowledged objective of governments to sustain coastal communities by providing capital and income subsidies to the fishing industry has undermined the success of past rationalization efforts (Schrank 2005).

SCIENCE ADVISORY AGENCIES

Concern about the effects of fishing on fish stocks was a primary motivation of the European scientists who established the International Council for the Exploration of the Sea (ICES) in 1902 (Went 1972), and this organization became the scientific advisory agency for the Northeast Atlantic fisheries commissions and for its member states. The governments of Canada, Newfoundland and the USA decided to form their own fishery science organization for the western North Atlantic, the North American Council on Fishery Investigations, in 1920 and were subsequently joined by France (NACFI 1932). NACFI became defunct with the outbreak of the Second World War and the fathers of ICNAF decided that the organization itself would coordinate the work of the research agencies of member states to ensure it received appropriate scientific advice. It established a Standing Committee on Research and Statistics (STACRES), composed of scientists from member countries, which provided critical peer review of scientific analyses and developed advice by consensus. The subsequent NAFO convention established a Scientific Council that operated on similar principles.

Prior to its 1977 extension of jurisdiction, Canada dealt with domestic fishery management issues as crises occurred and no mechanisms existed for the application of science to management on an ongoing basis. After jurisdictional extension, Canada could not continue to deal with its greatly expanded responsibilities on the same *ad hoc* basis as before. A domestic scientific advisory organization was created by the federal fisheries department in 1977, the Canadian Atlantic Fisheries Scientific Advisory Committee (CAFSAC). It was modelled on the STACRES of ICNAF, subcommittees providing technical review of scientific analyses and a steering committee providing co-ordination and policy guidance. CAFSAC was disbanded at the end of 1992 and its advisory role for groundfish was given to the new FRCC in 1993. The FRCC was composed of members of the fishing industry and non-government scientists. It was still the responsibility of DFO scientists to do the actual groundfish stock assessments and provide suites of regulatory

[2] Although a new policy for Atlantic fisheries (Kirby 1983), put forward in 1982, provided a blueprint for subsequent government actions to address economic and social problems in the industry (Parsons 1993b), it did not address conservation issues.

options for the FRCC to choose among, so the need for scientific peer review remained. Furthermore, CAFSAC had provided advice for all stocks, not just groundfish, and its demise eliminated the review mechanism for pelagic, invertebrate, marine mammal and freshwater fish stock assessments as well. Regional science branches initially established *ad hoc* arrangements for peer review of assessments that subsequently became formalized as a new Regional Advisory Process (RAP). The role of RAP broadened over time to one of advising on all marine conservation issues.

FISHERIES RESEARCH INSTITUTIONS, STAFF AND FACILITIES

The federal government has been responsible for almost all of the fisheries research conducted in Atlantic Canada. The organization of fundamental importance in shaping the history of research on fish and fisheries was the Fisheries Research Board of Canada (FRB) established in 1937. (For a history of the FRB and its predecessors, the Biological Board of Canada established in 1912 and the Board of Management created in 1898 see Johnstone (1977)). The FRB inherited Atlantic coast facilities that included a biological research laboratory in St Andrews, New Brunswick, originally established in 1908, and a laboratory in Halifax, Nova Scotia, that had been established in 1925 to conduct scientific research to improve the handling, processing and quality of fish products (for a history of the technological program, see Stewart & Safer (2005)). With Newfoundland's entry into confederation with Canada in 1949, its government laboratory that in various forms had been responsible for fisheries research in Newfoundland from 1931 was taken over by the FRB. In the early 1960s, the Bedford Institute of Oceanography, which included a new FRB laboratory for the study of marine ecology, was established in Dartmouth, Nova Scotia, and provided a major expansion in marine science on the Atlantic coast. The FRB laboratories were removed from Board control in 1973 and those involved in fisheries research were subsequently integrated into the regional fisheries administrations. These regional administrations had been developing their own applied research capabilities in the form of Resource Development branches and these were amalgamated with the fisheries research components of FRB to create new regional fisheries science branches. In general, the provinces have not engaged in marine fisheries research. The province of Quebec, however, has supported limited research on marine species as a result of the unique situation where some federal responsibilities for marine fisheries were delegated to it. University researchers played important roles in the initial establishment of Atlantic coast fisheries laboratories. From the 1990s, their role increased as the federal government provided financial encouragement for universities to take on aspects of the research that was within the mandate of federal laboratories. However, overall, universities have played only a minor role in fisheries research.

The numbers of professional scientific staff in Atlantic coast FRB laboratories were low in the early years, e.g. less than 10 at the Biological Station

in St. Andrews prior to the Second World War (Hart 1958). However, post-war, there was a substantial expansion (to 24 at the St. Andrews Station by 1954 (Hart 1958)). Needler (1984) attributed this to a positive change in public attitude towards research, resulting in greater demand at a time when government had more spending flexibility. The next big expansion in fisheries research occurred in the late 1970s when staff working on marine finfish doubled in support of the new responsibilities that came with extended fisheries jurisdiction, a need emphasized by a collapse of the groundfish stocks in the early 1970s. A gradual attrition followed from the mid 1980s to the present as research budgets were reduced and other priorities emerged.

The FRB did not pursue research on fishery economics, nor was such research included in the mandate of the Science branches subsequent to the early 1970s amalgamation with the fisheries department. Departmental economists resided within the operational part of the organization (primarily in Ottawa) and were largely involved in policy development rather than research. Although the comprehensive fisheries policy document produced in 1976 (DOE 1976) emphasized the importance of economic and social factors in achieving "best use" of fisheries resources, only a few new economics staff were hired, in contrast to the large increase in biological research (Parsons 1993a).

Vessels dedicated to research, and equipped with specialized gear and instrumentation, are essential for scientific research at sea. Commercial fishing boats sometimes can serve as satisfactory scientific observational platforms and in some specific cases are preferable but, for many tasks, they are not suitable. Prior to 1958, the largest vessels operated by the FRB Atlantic coast stations were only about 25 m long. These vessels were operated offshore at times, but their lack of facilities and seaworthiness was a severe limitation. The *A. T. Cameron*, a 54 m steel side trawler designed for research purposes, commissioned in 1958, was the first truly offshore Canadian Atlantic coast fisheries research vessel. A 40 m steel stern trawler, the *E. E. Prince*, was added to the fleet in 1966 but this vessel was designed for operation only in coastal and southern waters. The inadequacy of this research fleet was highlighted in preparations for the 1977 extension of jurisdiction. Two fishing trawlers converted for research purposes, the *Gadus Atlantica* and the *Lady Hammond*, were acquired immediately under long-term charters and a building program was initiated which resulted in the commissioning of two new research trawlers, the *Wilfred Templeman* in 1981 (which replaced the *A. T. Cameron*) and the *Alfred Needler* in 1982. These vessels were in the 50-80 m length range. The fleet was reduced in the early 1990s with decommissioning of the *E. E. Prince* and termination of the *Lady Hammond* charter. Of the three offshore vessels remaining in 2005, the *Alfred Needler, Wilfred Templeman* and *Teleost* (chartered to replace the *Gadus Atlantica* in 1995), one is scheduled for retirement.

FISHERIES RESEARCH

Prior to 1950

The effects of fishing on fish stocks was an active research topic in the early years of the 20th century and the modern theory of fishing was elaborated in the 1930s (Graham 1935). This theory stated that there was an exploitation rate that maximized the growth potential of a stock and that fishing beyond this level resulted in no further increase, or in a decrease, in yield. A corollary to this theory was that yield was a function also of the age at which fish were first caught. Yield would increase with increasing age at first capture as long as population increase due to growth exceeded loss due to natural mortality.

Research in Atlantic Canada was influenced by the early thinking that led to the theory of fishing and work was directed toward obtaining the information needed to understand the dynamics of populations. In the earliest years, work at the St. Andrews laboratory was by volunteer investigators from the universities and was broadly exploratory emphasizing studies of the fauna and flora and their life-histories. However, by the 1920s, the need for more concentration on practical fisheries problems led to the hiring of full-time staff, and research effort focussed on resources of commercial importance and to the development of fishing gears. Examples of work of practical importance to marine fisheries include (from Hart (1958) unless referenced otherwise):

- the Canadian Fisheries Expedition in 1914-15 led by Johann Hjort that explored the biology of herring in relation to oceanographic conditions
- the comprehensive description of the interrelationships of haddock stocks in the late 1920s (Needler 1930)
- the early 1930s study of the effects of tidal power projects on the Bay of Fundy herring fisheries
- the description of the biology of cod and haddock in the Newfoundland area (Thompson 1939, 1943)
- the early 1940s promotion of new groundfish fishing methods to increase fishing efficiency.

According to its Annual Report for 1950, the work of the St. Andrews Biological Station was "to provide, through research, the basis for maintaining and increasing the supplies of raw materials for the fishing industry and for making them more available by improving catching methods" (Needler 1950). This was to be done by "exploration for new resources, discovery of the basis for regulating intensive fisheries to assure the maximum long-term yield, improvement of methods of increasing production by positive cultivation, and developing and testing of more effective means of finding and catching fish".

1950 to 1990

The yield-per-recruit theory of Beverton and Holt (1957) and the methodologies they elaborated allowed the quantification of yield expected from a particular fish stock corresponding to any level of overall fishing mortality and age at first capture. This was just the set of tools scientists' needed to apply the theory of fishing. It provided a basis for giving quantitative advice on regulatory requirements to the new international fisheries commissions. Yield-per-recruit modelling of fish population dynamics became the predominant methodology for determining the status of fish stocks.

The post-war staff increases allowed the greatly expanded data collection on the commercial fisheries that was necessary for the application of these new scientific methods. A program was initiated to sample the sizes and ages of fish in commercial landings using samplers in the main ports, and a fishermen's logbook system was established that recorded the area in which fish were caught (rather than port of landing) and the amount of fishing effort expended to make the catch. These long-term monitoring programs continue today, although the logbook system was taken over by the operations side, which was already responsible for landings statistics, in the late 1970s. Research was intensified on stock structure and on the biological parameters of stocks such as their growth, sexual maturation and mortality rates.

The first issue on the ICNAF agenda was to reduce the wastage of fish at sea that resulted from the discarding by otter trawlers, the predominant gear used, of those fish that were too small to market. Although it was known that the size of the meshes in the netting in the codend part of the trawl influenced the size of fish retained, the precise relationships between mesh size and the size of fish caught had to be described by experiments at sea (ICNAF 1963, Holden 1971). It was found that many aspects of trawl construction affected this relationship, particularly netting material (the different types of natural and synthetic fibres) and gear construction, particularly chafing gears (materials attached to codends to reduce damage to netting) (McCracken 1960). The growth and mortality of each of the fish stocks had also to be described, as well as the size and age composition of catches, so that the changes in yield to be expected from increasing mesh size could be worked out using yield-per-recruit models. While the first regulation of mesh size came into effect in 1953, there were many causes for uncertainty about whether increasing mesh size would in actuality improve yields. However, it seemed likely to be beneficial if for no other reason than that the efficiency of fishing operations would be increased from not having to throw large quantities of fish over the side (Graham 1952). It was not until 1961 that ICNAF's scientific committee was able to give a definitive statement on the expected benefits from mesh regulation in the groundfish fisheries (Beverton & Hodder 1962) and 1968 before the full extent of the research was reflected in regulations.

By the 1960s, it was becoming increasingly clear to ICNAF that action on the central tenet of the theory of fishing, control of the amount of fishing

effort, was essential. There were two ways to control the amount of fishing effort, either directly by limiting the time vessels spent fishing or by limiting the amounts of fish caught. The scientific problems involved in applying one or the other of these methods were quite different. Direct control of fishing effort required inter-calibrating the many different vessel and gear types in use in terms of the mortality they generated per unit of fishing activity and keeping track of changes in technology and fishing behaviour that might affect the ability of a fishing unit to generate fish mortality. Control of catch required prediction of the catch in the next fishing year that would cause the desired level of fishing mortality. This necessitated that the absolute size of the fish stock be estimated. The issue was very largely settled by ICNAF deciding that catch limits were the simpler solution from a multinational political/administrative perspective. Collapse of the haddock stocks in the late 1960s caused ICNAF to set TAC limits for them in 1970 and by 1974 all of the major directed fisheries in the Northwest Atlantic were under TAC regulation. Nonetheless, there were subsequent attempts to introduce direct fishing effort control. Thorough investigation by USA scientists in the early 1970s supported regulatory proposals for effort limitation for Subarea 5 (Fig 3) and adjacent waters to the south, to be implemented in addition to catch limitation. However, the USA proposals were technically too complex to obtain acceptance within ICNAF. A much simpler proposal was subsequently devised by Canadian scientists for Subareas 2-4 and was implemented for 1976, but the initiative was not sustained after Canada's extension of jurisdiction.

New scientific methods were developed that allowed the absolute size of fish stocks to be calculated and next year's catch to be projected, in support of TAC regulation. These methods are categorized as Sequential Population Analyses (SPA), original versions being called Virtual Population Analysis (Gulland 1965) and Cohort Analysis (Pope 1972). These methods require knowledge of commercial catches in number by age group for at least several previous years, and fishing mortality in the most recent year. Estimating catches by age group requires accurate estimates of total catch tonnages by stock area and biological samples from the catches of each country by gear type and season, because age composition varies by these factors. Estimates of total mortality could be obtained from the changes in catch rates of commercial vessels from one year to the next for specific year-classes or cohorts. Fishing mortality could then be calculated by subtracting natural mortality from this total mortality estimate. Natural mortality was not well estimated but appeared to be low compared to fishing mortality and results were not expected to be greatly affected by this uncertainty (an assumption that came to be regretted in later years – see below).

Initial concerns in application of the SPA and catch projection method to Northwest Atlantic stocks were related to lack or incompleteness of data. While Canadian port sampling and fishery statistics programs had been in place for some years, various other countries were ill-equipped to meet the data collection requirements for TAC regulation. Biological sampling of

catches was particularly problematic for countries whose vessels processed catches at sea. Obtaining estimates of quantities discarded at sea proved to be an intractable problem (although not for freezer trawlers, which processed virtually everything). Another difficulty in projection was accounting for the strength of new year-classes entering the fishery during the projection period and it was necessary to assume that future recruitment would be similar to that observed in the past. This was an important issue for short-lived species, such as silver hake, for which recruiting year-classes formed an important part of the projected catch.

Initially, time series of commercial catch rates were depended upon to calibrate, or 'tune', SPA estimates of present stock size, but many factors could cause changes in catch rates other than population abundance and it was anticipated that the imposition of catch (or effort) controls would make this approach even less reliable. Scientists from the USA had initiated a series of standardized research vessel bottom trawl surveys off New England in 1963 that provided fishery-independent estimates of stock abundance. As small mesh nets were used, these also provided estimates of the strength of recruiting year classes. Such surveys offered a solution to the issues of SPA tuning and catch forecasting and, at the beginning of the 1970s, ICNAF adopted a program to extend their geographic scope to the entire Northwest Atlantic, a goal achieved by the end of the decade (Doubleday & Rivard 1981, Doubleday 1981). These surveys initially supplemented and gradually supplanted commercial catch rates for calibrating SPAs. In addition, the initial subjective approaches to calibration were replaced by more statistically rigorous methods for calculating commercial catch rates (Gavaris 1980) and for SPA calibration (Gavaris 1988) and methods of estimating the uncertainty of model projections were developed (Smith et al. 1993). Deficiencies in data on foreign commercial fisheries were addressed by establishment in 1979 of an International Observer Program that put Canadian observers aboard foreign boats fishing in the Canadian zone to collect biological data on catches and information for enforcement purposes. This program was subsequently extended to the domestic fleet.

While maintaining and improving the short-term projection procedure in support of the TAC management system became a major element of the science program for finfish management from the early 1970s, other research was not completely ignored. It was thought that the primary deficiency of the yield per recruit methodology being used to provide advice was that it did not take into account the factors affecting recruitment, which was the primary determinant of fish stock production. There were two main approaches to this problem, the first being to relate parent stock size with subsequent recruitment by fitting mathematical models to data from the fisheries (see below) and the second to conduct field experiments to determine the mechanisms involved in determining year-class success. In the Northwest Atlantic, the first large scale field program to try to link recruitment to parent stock or environmental effects was conducted in 1965-74 for cod in the southern Gulf of St. Lawrence (Lett et al. 1975). This was

followed in the late 1970s by similar multi-national studies, sponsored by ICNAF/NAFO, on Georges Bank herring (Grosslein 1987) and Flemish Cap cod and redfish (Lilly 1987). Canadian scientists participated extensively in these initiatives. On the Scotian Shelf, where almost nothing was known about the spatial and temporal distribution of fish eggs and larvae, a series of broad-scale surveys were conducted in 1977-82 (the Scotian Shelf Ichthyoplankton Program) (O'Boyle et al. 1984, Sinclair 1988). This served, in part, as a basis for a Fisheries Ecology Program that conducted field sampling off southwest Nova Scotia in 1983-85 (Smith et al. 1989). Although these very expensive field programs generated a great deal of valuable information about the species and areas studied, they unfortunately contributed little to understanding the causes of recruitment variability. By the mid 1980s, budgets for fisheries science were being reduced and program scope had narrowed, essentially, to research directly in support of stock assessment.

Gear research and development, and exploratory fishing for species not utilized by the Canadian industry, continued to be of importance within the science program in the 1960s. Subsequently, these activities became insignificant within science programs, but they were continued within 'industrial development' branches established within the operations side of the organization. Increasingly, in the 1980s and subsequently, development-type research was directed to conservation-related issues such as reducing bycatches and the catches of small fish, e.g. by demonstrating the benefits of using square mesh netting (Halliday et al. 1999) and sorting grids in trawl nets (Halliday & Cooper 1999).

1990 to Present

As already mentioned, ICNAF's objective was to obtain MSY, equated to F_{max}, but Canada adopted a strategy of fishing at $F_{0.1}$, the most conservative strategy among those adopted by national and international management agencies throughout the North Atlantic (Halliday & Pinhorn 1996). Nonetheless, it was the groundfish stocks in the Canadian zone that collapsed catastrophically in the early 1990s. Although frequently portrayed as the collapse of the cod stocks, other stocks of both commercial and non-commercial groundfish species also collapsed, particularly in the northern part of the zone. While the history of the fisheries is one of lurching from one crisis to another, this collapse was in a class of its own and created great economic and social hardship, particularly in Newfoundland.

This collapse of the groundfish stocks was not foreseen by the scientific community and created a crisis of confidence in CAFSAC, its scientific advisory body. The degree of dissatisfaction with scientific advice was reflected, for example, by the Minister taking the responsibility for providing advice on groundfish management from his departmental scientists and placing it in the hands of an outside body, the FRCC (see above under Fisheries Management).

Explanations put forward for the early 1990s groundfish collapse were overfishing, a large-scale environmental change or some combination of these factors. The primary debate centred on the large cod stock off Labrador and eastern Newfoundland, the 'Northern cod'. The initial interpretation of its collapse was that there had been a sudden, substantial increase in natural mortality due to ecosystem changes (Lear & Parsons 1993, Atkinson & Bennett 1994). However, this was soon refuted in analyses that attributed the decline to fishing mortality alone (Hutchings & Myers 1994, Hutchings 1996). Public opinion (including fishermen's organizations and many academic and applied fisheries scientists) was overwhelmingly in favour of a view that over-fishing and overfishing alone was the cause of the collapse. CAFSAC advice that gave credence to other explanations was characterized as evidence of bureaucratic interference in the advisory process (Hutchings et al. 1997a). (See also rebuttal by Doubleday et al. (1997) and reply by Hutchings et al. (1997b).) The Northern cod collapse came to be viewed internationally as a prime example of the disastrous effects of overfishing.

How could this have happened in such a highly regulated and monitored regime? Scientists had become aware in the mid 1980s that the new statistical methods for tuning SPAs were prone to biases in estimates of current stock size, likely due to data deficiencies (Sinclair et al. 1985, 1990). Initial estimates retrospectively proved most often to be too high, causing TACs to be set too high in relation to the $F_{0.1}$ reference point. This 'retrospective problem' clearly contributed to exploitation rate being higher than intended, a problem compounded by deficiencies in the control of fishing, see e.g. Angel et al. (1994). Nonetheless, one of the reasons $F_{0.1}$ was chosen as a reference point was to make allowance for just such deficiencies. The Fs estimated for Canadian cod stocks in the 1980s were a bit above F_{max}, the lowest for cod in any of the North Atlantic management regimes in that period (Halliday & Pinhorn 1996). Arguments can be made that these F estimates are unreliable, but if they are given credence, it seems unlikely that high F was the cause of the collapse of Canadian stocks while those elsewhere did not suffer a similar failure.

There is scope for an argument that the large scale overfishing occurred not during the 1980s but over a brief period in the early 1990s. For example, unreported catches were seen by Shelton & Lilly (2000) as the most plausible explanation for the collapse of the Northern cod. Nonetheless, they found it disconcerting that their estimate of the amount of fish missing from the statistical record was larger than the combined catching capacity of the Canadian and foreign fleets, and thus were forced to recognize that other factors were also involved.

In keeping with the view that the groundfish stock collapses were primarily, or perhaps entirely, due to fishing, the limitations of yield-per-recruit methods came to the fore in stock assessment evaluations and, in particular, the fact that they did not take into account the effect of spawning stock size on recruitment. Some scientists thought that if stock assessments had

included reference points for minimum spawning stock sizes the collapses might have been avoided. The large-scale field studies in the late 1970s – early 1980s had not been successful in determining the causes of recruitment variability (see above), leaving the modelling of relationships between parent stock and subsequent recruitment from fisheries-related data as the only avenue of pursuit. Unfortunately, the variability in observational data for teleost fishes makes a statistical relationship between spawning stock and subsequent recruitment essentially impossible to discern, requiring that the form of the relationship be assumed. Making assumptions about the form of stock-recruitment relationships was tolerated for exploratory scientific modelling, but to actually use such assumptions as a basis for management advice was long seen as unjustifiable. However, the United Nations agreement relating to the conservation and management of straddling fish stocks and highly migratory fish stocks in 1995 (United Nations 1995), which resurrected MSY as the foundation for reference points for application of the precautionary approach, gave licence to ignore these longstanding reservations. Much effort in recent years has been put into defining reference points for spawning stock biomass as central elements of decision rules for setting allowable catches for each stock.

An alternative school of thought developed in the late 1990s that rejected yet more complex theory-based modelling of single stocks as the basis for scientific advice. These scientists thought that having the key reference points on which fisheries would be opened and closed based on no more than assumptions was not a reliable basis for management and that this approach gave false assurances to fisheries managers and the fishing industry about sustainability. They proposed data-based alternatives that depended more heavily on biological knowledge. The Traffic Light Method (Caddy 1999) was one such alternative that received considerable scientific attention (Halliday et al. 2001). This method establishes a precautionary decision framework based on a multiplicity of indicators based on biological, fishery and environmental data (and can include the outputs from complex assessment models). The Traffic Light approach has been applied in some cases where there were insufficient data to allow the use of mathematical modelling, such as assessments for shrimp (Koeller et al. 2000) and crab (Caddy et al. 2005), but has not yet been accepted as a preferred alternative to reliance on traditional methods.

The groundfish stock collapses also caused a renewal of research interest within the fisheries science community in biological and ecological questions, rather than simply single species stock dynamics. Studies illustrated that the late 1980s – early 1990s decrease in groundfish populations were broadly coincidental with large changes in all elements of the ecosystem, physical oceanography, phytoplankton, zooplankton, pelagic fishes and benthic invertebrates (e.g. Frank et al. 2006, DFO 2003). Causes of the many changes observed in the biological characteristics of groundfish stocks prior to and during their collapse were studied and the assumptions underlying assessment models were re-examined. Of particular note in

this latter regard was the discovery that natural mortality of cod had been much higher than previously thought in southern Gulf of St. Lawrence cod (Sinclair 2001). This insight was based on estimates of total mortality from research vessel surveys, which could be attributed to natural mortality, fishing mortality being negligible due to fishery closures. (A new method of estimating natural mortality from SPA (Chouinard et al. 2005) has since confirmed Sinclair's results.) Applying Sinclair's method to other stocks showed that natural mortality in the early 1990s for at least some cod stocks was likely sufficiently high to alone account for their collapse. Laboratory and field investigations of causes for this increase in natural mortality illustrated that a reduction in fish condition (the ratio of weight to length) was a prime candidate (Dutil & Lambert 2000). It can be hypothesized that oceanographic changes caused large-scale distributional shifts (Rose et al. 1994, Kulka et al. 1995, Castonguay et al. 1999) that resulted in reduced food availability, a consequent decline in condition and elevated over-wintering and post-spawning mortality. Predation on cod by expanding seal populations was examined as another possible contributory factor for higher cod mortality. While deemed not to have been a major factor in the initial collapse, seal predation could be an impediment to stock recoveries (Mohn & Bowen 1996, Fu et al 2001, Chouinard et al. 2005). These observations provide support for a strong environmental contribution to the 1990s ecosystem disruptions.

Increasingly, scientists have found it necessary to admit that overfishing was not the sole cause of the early 1990s groundfish stock collapses, but the conventionally accepted explanation remains that fishing was, nonetheless, the primary causative factor, see e.g. Rice (2002). It may never be possible to give a definitive answer to the respective roles of fishing and the environment in this event. However, it seems likely that the key role of environmental change in causing the collapses will come to be more fully appreciated.

DISCUSSION

Fisheries science has benefited from its beginnings in the early 20th century from rapid exchange of ideas and strong international cooperation fostered through science and management institutions such as ICES and the fisheries commissions. The science for Canadian Atlantic coast fisheries did not differ greatly from that for fisheries off Europe and elsewhere. The ICNAF initiative to institute a Northwest Atlantic standardized bottom-trawl survey program using research vessels proved foresighted and was adopted elsewhere. These surveys have provided a platform for broad-scale ecosystem monitoring, the importance of which became increasingly well recognized after fishery closures, and as management of uses of the ocean generally became a focus of interest with passage of Canada's Oceans Act in 1997. The Canadian introduction of observers on most foreign vessels fishing in its zone from 1979, and subsequently on domestic vessels, was also unique

among North Atlantic management regimes in its scale of application. It provided data valuable for research when coverage approached 100% but its dual role of enforcement and scientific data collection compromised its usefulness to scientists in other cases.

There was also commonality in regulatory approaches by North Atlantic management authorities. Although ICNAF was the first to embark upon catch controls, as a political imperative in the face of rapidly increasing international fishing effort and collapsing fisheries, it was immediately followed by the North-East Atlantic Fisheries Commission. Domestic fisheries jurisdictions in general maintained continuity with the practices of the international commissions at the time of their jurisdictional extensions; Canada was not exceptional in this regard.

The science community was ill-equipped to support the international commissions' TAC initiatives. New scientific methods were rapidly developed and immediately applied, using data that suffered from many inadequacies, and there was no scope for evaluating the accuracy of the advice given in the relatively short time before the establishment of national jurisdictions. In Canada's case, the coincidence of groundfish stock recovery with extension of jurisdiction encouraged a view that the TAC system was indeed working, and that a large investment in a short-term catch forecasting service, as the basis for optimal exploitation ("best use") of the resources, was worthwhile.

In retrospect, there are reasons to question whether this singular preoccupation with accurate catch forecasting was the best use of scientific resources. The uncertainty in scientific advice remains high, despite 30 years of continuous development of methods, and is unlikely to improve due to the variability inherent to fisheries and survey data (see, e.g. National Research Council (US) (1998)). The reliability of catch projections is too low to make annual adjustments in TACs to maintain fishing mortality rates at $F_{0.1}$, or some other reference point, a practical endeavour. (Nor is the regulatory system capable of controlling catches with a level of precision compatible with optimal exploitation – which contributes to assessment uncertainties.) More general scientific guidance for management would be less costly and more useful for being less likely to mislead.

The wisdom of the decisions being made in scientific advisory bodies to implement the precautionary approach using model-based limit reference points for spawning stock sizes is also open to question. The methodology utilizes stock assessment output data and introduces more assumptions to those that already underlie the assessment. An application of the precautionary approach, to be consistent with Annex II of the 1995 UN Fisheries Agreement (United Nations 1995), requires that these limit reference points trigger pre-agreed conservation and management actions, such as the opening and closing of a fishery. Decisions of such economic and social importance should be based on sounder footings. Schnute & Richards (2001) provide an invaluable perspective on the use and abuse of fishery models in the provision of scientific advice and warn against the practice

of depending on the output from single models. Caddy (2002) has noted that the precautionary approach issue has provided scientists with much scope for career enhancement through production of scientific papers, but that the focus on resolving scientific issues about indicators has diverted attention away from involving the industry and managers in developing frameworks for taking action. Decision frameworks using readily available, data-based indicators that fishermen and managers can understand, are the ones likely to obtain the support of industry and thus have some positive practical effect.

Most importantly perhaps, a singular focus on description of the dynamics of individual stocks and the effects of fishing axiomatically precludes recognition of excluded factors that may have equal or greater effects on stock abundance. This is simply a repetition of a long-standing criticism of single-species stock assessment. However, the controversy over the causes of the early 1990s collapse of the groundfish fisheries emphasises the need for a return to a broader-based fisheries science that puts fish stocks in the context of their ecosystem. This requires research through field data collection and laboratory experimentation to provide knowledge of cause and effect, and the use of mathematical models as research tools for evaluating hypotheses.

Appropriate institutional arrangements are the key to success in fishery management, as in all such endeavours. The regionalization of fisheries science in the mid-1970s fractionated science, but did not effectively integrate science and operations within regional management organizations. Successful implementation of fisheries policies and plans requires adoption of an operations research, now known as a management science, approach to policy implementation (Lane & Stephenson 1999). New institutional arrangements that put an operational research function in the middle between traditional science and operations units, analogous to much earlier proposals, e.g. in a Canadian context by Regier & McCracken (1975) and generally by Edwards (1981), offer a constructive way forward.

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MARINE ECOSYSTEM ASSESSMENT: PAST, PRESENT AND FUTURE ATTEMPTS WITH EMPHASIS ON THE EASTERN SCOTIAN SHELF

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The collapse of major fish stocks around the world, their failure to recover even after the cessation of fishing, and the perceived deficiencies in single species fisheries management has resulted in an intensified interest in the study of whole systems. Assessment of ecosystems is a relatively new phenomenon and represents a significant departure from the past focus on individual ecosystem components such as individual, commercially-exploited stocks of fish and invertebrates in isolation from their physical, chemical and biological environment. A report entitled "State of the Eastern Scotian Shelf Ecosystem" was completed recently and some of its main findings form the body of this paper. The analysis focused on more than 60 data series, most extending back to at least 1970, associated with three categories of variables: biotic, abiotic and human. Biotic variables included the abundance, distribution and composition of finfish and invertebrates, phyto- and zooplankton, and marine mammals. Abiotic variables included oceanic and atmospheric data that specify ocean climate conditions. Human variables ranged from fisheries landings and revenue, activities associated with oil and gas development and contaminants. By examining temporal variations in the data, an assessment was made of the current status of the ecosystem relative to its past state.

L'effondrement de stocks de poissons importants partout dans le monde, l'incapacité de ces stocks à se rétablir même après l'arrêt de toute activité de pêche et les lacunes perçues dans la gestion des pêches axées sur une espèce ont donné lieu à une hausse de l'intérêt pour les études écosystémiques. L'évaluation des écosystèmes est un domaine relativement nouveau et constitue un changement d'orientation considérable par rapport à l'importance accordée par le passé aux composantes individuelles des écosystèmes, comme les stocks de poissons et d'invertébrés particuliers exploités à des fins commerciales sans tenir compte de leur milieu physique, chimique et biologique. Un rapport intitulé « État de l'écosystème de l'est du plateau néo-écossais » a été parachevé récemment, et certaines des principales conclusions présentées dans ce rapport constituent le corps du présent document. L'analyse a porté sur trois catégories de facteurs (biotiques, abiotiques et anthropiques) dans plus de 60 jeux de données, la plupart remontant au minimum à 1970. Les variables biotiques sont notamment l'abondance et la répartition des poissons, des invertébrés, du phytoplancton, du zooplancton et des mammifères marins, ainsi que la composition de leurs communautés. Les variables abiotiques comprennent les données océaniques et atmosphériques qui permettent de comprendre le climat océanique. Les facteurs anthropiques englobent les prises de poisson, les revenus de pêche, les activités liées à la mise en valeur du pétrole et du gaz et les contaminants. L'examen des tendances temporelles dans les données a permis d'évaluer l'état actuel de l'écosystème par rapport à son état antérieur.

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INTRODUCTION

Is it possible to assess the status of large, complexly inter-woven, multi-dimensional and multi-causal systems? What pre-conditions are required for such an assessment to be successful and useful? These are the main issues that we wish to examine in light of a recent attempt by the Canadian Department of Fisheries and Oceans (DFO) to produce such an integrated assessment of the status of a large ocean area, the eastern Scotian Shelf ecosystem.

What exactly is meant by "assessment"? To assess generally refers to an evaluation of the magnitude and quality of some object. The word frequently is used in the context of economics (e.g., for the purposes of valuation and taxation) and medicine (e.g., an assessment of the health of an individual). In the ecological context, both connotations of the word are used. The economic connotation is represented by an evolving field of what is known as "ecological-economics" where the focus is on evaluating the monetary value of various ecological structures and functions (e.g., What is the monetary value of clean-air or the function of forests in maintaining the global carbon cycle for the purposes of a "carbon" tax, or some undiscovered plant's disease prevention capacity). The medical connotation is represented by another recently evolving field that is concerned with "ecological health" (e.g., Are there indicators of ecosystem health just as there are indicators of human physiological, psychological or even spiritual health, or distress?). It is not yet clear which of these two models, ecological economics or ecological health, is more appropriate in an ecological context. In fact, both models may be necessary for the further development of ecological assessments as the tension between the economic model, which is decidedly more reductionist in perspective, and the medical model, which is more synthetic, may foster creativity and deeper knowledge of ecological assessment.

Why the desire to assess the status of ecosystems? With the ever-increasing human modification of ecosystems, the public consciousness of their dependence upon the ecosystems in which they live has become more widespread and vocal. The social, economic and political consequences of environmental and ecological disasters are proving to be tremendous forces that are difficult to ignore because of their direct and indirect influences upon our own health and wealth (e.g., oil spills, groundwater contamination, food contamination and bioaccumulation of toxic chemicals, radiation poisoning, invasive species, fisheries collapses, agricultural collapse, rapid climate change). In marine systems, the collapse of major fish stocks around the world, their failure to recover even after the cessation of fishing, and the perceived deficiencies in single species fisheries management has resulted in an intensified interest in the study of whole systems. The issue is: will continued or increased human modification and exploitation of the ecosystem or part thereof, result in some calamity that will damage our health and wealth? This question stands behind the popular call for sustainability and minimal ecological footprints or impacts.

While the demand for some comprehensive and comprehensible assessment is ever-increasing, the mechanisms by which such demands may be met are lacking. The scientists that are called upon to provide such assessments work in a social, political and economic atmosphere that fosters extreme specialization. For example, most marine scientists study particular aspects of the biology, chemistry or physics of the ocean. Among each of these broad categories there is a finer degree of specialization so that within the realm of marine biology, for example, individuals focus on fish, plankton, whales and so on. The division continues, often to the level of functional grouping of species such as groundfish, pelagic fishes (either large or small ones such as tuna and swordfish versus mackerel and herring), zooplankton, phytoplankton and benthic invertebrates to name just a few. In government laboratories further refinement occurs with specialists for individual species, particularly among those species that are commercially exploited. The need to provide scientific advice to fisheries managers, participation in species-specific working groups, symposia and scientific journals tend to reinforce the commitment to research at such a specialized level.

This tendency to hyper-specialization is further exacerbated by the natural complexity of ecosystems. There are many types of organisms that each behave in complex and interdependent ways. This complexity in behavior becomes more apparent the more a particular organism (singular) is studied. This onslaught of information makes its synthesis into an integrated whole all the more challenging. To satisfy the demands of some scientists for reliable and complete information to understand, describe and provide assessments of an ecosystem would require resources beyond what could reasonably be expected. Further, as the total resources available is a strong limiting constraint, there is an inverse relationship between spatial and temporal coverage in research and in monitoring programs – more research, less monitoring and vice versa. With even the simplest of assessments many assumptions are required thereby reducing the reliability of any extrapolation.

Even if near-perfect information were somehow available to assess the status of an ecosystem, the science of "complexity" and non-linear dynamical systems theory of more recent years indicate that there is a rapid diminishing of returns in understanding a complex system for each bit of information gained. Even after years of focused research of the much "simpler" and better understood climatological processes, large uncertainties exist with even the best forecasts. What then are the chances for a biologist to produce an assessment of a hyper-complex ecosystem with any real rigor, reliability or authority?

It is not surprising, therefore, that there have been few attempts to assess either communities of organisms or entire ecosystems. Some attempts have been made by pioneering ecologists such as Raymond Lindeman (1942), Eugene Odum (1968, 1969), Howard Odum (1971, 1983), Bernard Patten (1971, 1982), David Schindler (1990) and John Steele (1985) as well as

through large international efforts such as the International Biological Program, but these attempts have always fallen short, because of the unforgiving complexity of natural ecosystems and limited funding (the agencies may have been strongly motivated to fund but did not have the means to do so). Recently through the activities of the Smithsonian Institution and numerous co-operating agencies, long-term monitoring of large areas has been established throughout the world [Decision Support System for Sustainable **Eco**system **Man**agement in Atlantic Rain Forest Rural Areas (ECOMAN)] in an attempt to consolidate existing observations and to extend them in time through additional measurements. ECOMAN has focused mostly on the terrestrial environment. In aquatic systems, long-term freshwater studies have been and continue to be a field of active research led by such notables as Henry Regier (1973, 1996), R A Vollenweider (1976), and David Schindler (1990). In the much larger marine systems, considerably less has been done, but the situation is changing, particularly due to the efforts of Kenneth Sherman and his Large Marine Ecosystem (LME) initiative that began in the late 1980s. His approach has been to assess the ecological state of LMEs using a case-study approach to examine the causes and effects of environmental and human-induced changes of ecosystem productivity (e.g. see Sherman & Skjoldal 2002). While the initiative has met with mixed success it has stimulated the assembly and analysis of a broad base of environmental data.

Over 30 years ago, Canadian government laboratories made a commitment to long term and large scale monitoring of various components of the marine ecosystem using standardized methods of sampling. The availability of this high-quality information has allowed a first attempt at a comprehensive, integrated assessment of the current status of a large ocean area or ecosystem under Canadian jurisdiction. In the past, the focus has been on the examination of individual ecosystem components such as individual, commercially-exploited stocks of fish and invertebrates, the physical and biological environment, and various status reports (e.g. contaminants). A report entitled "State of the Eastern Scotian Shelf Ecosystem" (DFO 2003) was completed by a dedicated team of specialists and synthesizes much of the information available for the area. Its findings form the body of the remainder of this paper.

The State of the Ecosystem report was a product of a working group that compiled and analyzed various data relevant to the evaluation of the eastern Scotian Shelf ecosystem. The analysis focused on more than 60 data series, most extending back to at least 1970, associated with three categories of variables: biotic, abiotic and human. Biotic variables included the abundance, distribution and composition of finfish and invertebrates, phyto- and zooplankton, and marine mammals. Abiotic variables included oceanic and atmospheric data that specified ocean climate conditions. Human variables ranged from fishery landings and revenue to activities associated with oil and gas development and contaminants. By examining temporal variations of the data, an assessment was made of the current status of the ecosystem relative to its past.

METHODS

Study area

The Eastern Scotian Shelf (ESS), comprising Northwest Atlantic Fisheries Organization (NAFO) Division 4VW, is a large geographic area (~108,000 km^2) supporting a wide range of uses such as fisheries, oil and gas exploration and development, and shipping (Fig 1). It is currently the focus of the development of an integrated management plan with the intent to harmonize the conduct of the various ocean activities within it (referred to as ESSIM: Eastern Scotian Shelf Integrated Management). The ESS consists of a series of outer shallow banks and inner basins separated by gullies and channels. The mean surface circulation is dominated by southwestward flow, much of which originates from the Gulf of St. Lawrence with anticyclonic (clockwise) circulation tending to occur over the banks and cyclonic (counter-clockwise) circulation around the basins. The northeastern region of the Shelf is the southern limit of winter sea ice in the Atlantic Ocean. The area is unique for having a year-round closure for directed fishing of groundfish established in 1987, located over Emerald and Western Banks. In addition, DFO has declared The Gully region (see Fig 1) as a pilot marine protected area. Like several other areas in the northwest Atlantic, the dominant cod fishery collapsed in the early 1990s.

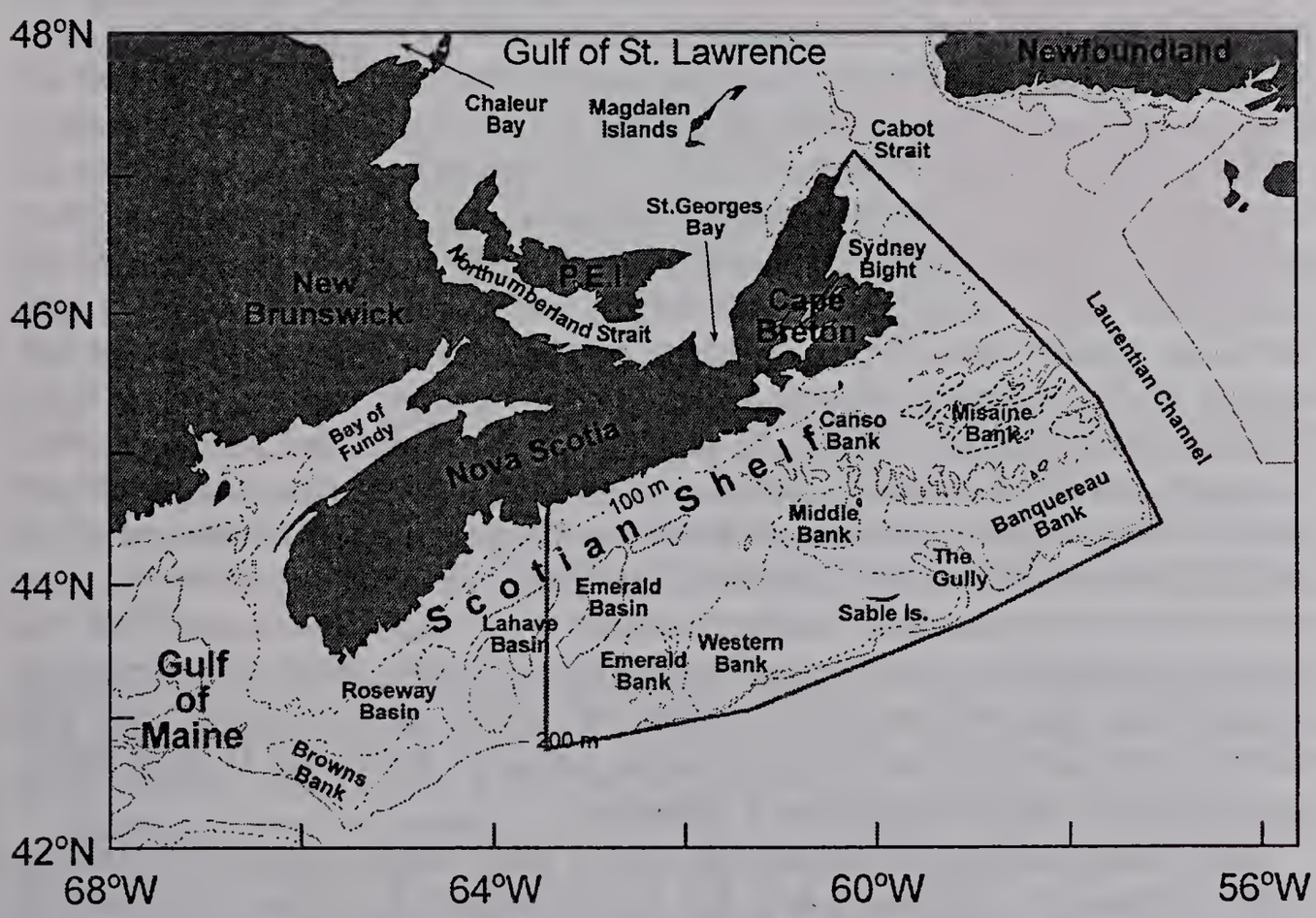

Fig 1 The study area. The line defines the Eastern Scotian Shelf region. No consideration was given to the nearshore zone.

Data: analysis and integration

An overall picture of the changes that have taken place on the Eastern Scotian Shelf since 1970 was addressed by adopting an approach similar to the traffic light framework now being applied in stock assessments (i.e. a stepwise application of precautions) and recently used by Link et al. (2002) for an ecosystem evaluation in a fisheries management context of Georges Bank. Time series of sixty-four metrics were used in the evaluation with 50 representing primary indices and 14 indicative of second order indices, i.e. higher level processes such as community composition, ratios of variables or growth. The indices were made directly comparable to one another by expression as anomalies (deviation from long-term mean) in standard deviation units. Colors were used to display the magnitude of the anomalies ranging from strongly negative (below the long-term mean, red) to strongly positive (above the long-term mean, green). The series were ordered using principal components analysis to identify any coherence in their variability over the study period. Thus, the sequence of the indicators reflects the degree of similarity in their temporal dynamics (Fig 2).

RESULTS AND DISCUSSION

Ecosystem changes

Seal abundance, pelagic fish abundance, landed value of shellfish, fish species richness and phytoplankton (the continuous plankton recorder (CPR) color index) were among the metrics that changed in a coherent manner relative to those further down the list during the 1970s to the early 1980s period. These metrics initially had negative values (anomalies). Subsequently, they shifted to positive values in the 1990s where they have remained to the present. Conversely, anomalies of bottom temperatures at Misaine Bank, commercial exploitation levels, groundfish landings and biomass, growth rates of cod, haddock and pollock, average individual fish weight and copepod (*Calanus finmarchicus*) counts, were positive from the 1970s to the early 1980s. In addition to warm bottom temperatures, a weakly-stratified summer water column and a deep mixed-layer depth typified the abiotic conditions at this time. During the 1990s almost all of the positive anomalies for these biotic variables became negative at a time when bottom temperature declined, mixed layer depth decreased and the water column became more stratified. What is visually striking is the change in state from one extreme to the other for almost all the metrics over the study period, with the transition occurring between the years 1985 to 1990. The changes were systemic and coherent.

The causes of the reciprocal changes in abundance among alternating trophic levels is consistent with the hypothesis of top-down or predator control of food webs – the so-called trophic cascade (Fig 3) (Frank et al. 2005). When the indicators of groundfish abundance were high during the 1970s/mid-1980s, small pelagic fish abundance was low, zooplankton abundance was high and chlorophyll was low. Throughout the 1990s, this pattern

Fig 2 The matrix of time series of annual anomalies of variables considered in the case study and ordered according to their similarity of responses to one another. The ordering was based on a principal components analysis and the visualization reveals a clear shift in the state of the eastern Scotian Shelf ecosystem. Green blocks (cells) indicate above normal conditions, red below normal conditions, and white normal or missing data.

reversed with groundfish abundance low, pelagics high, zooplankton low and phytoplankton high. Changes in ocean climate (described in the next section) have also played a role in the dynamics of the fish community.

Seals have been repeatedly blamed for the changes that have occurred within the groundfish community, most notably the collapse of cod. However, their increases have matched the increases in the pelagic fish community indicating a likely response to large scale ecosystem changes on the Scotian Shelf. In fact, seals may be a moderating influence, reducing the complete dominance of pelagic fish. Furthermore, the proportion of cod in the seal diet has been re-estimated for recent years based on quantitative fatty

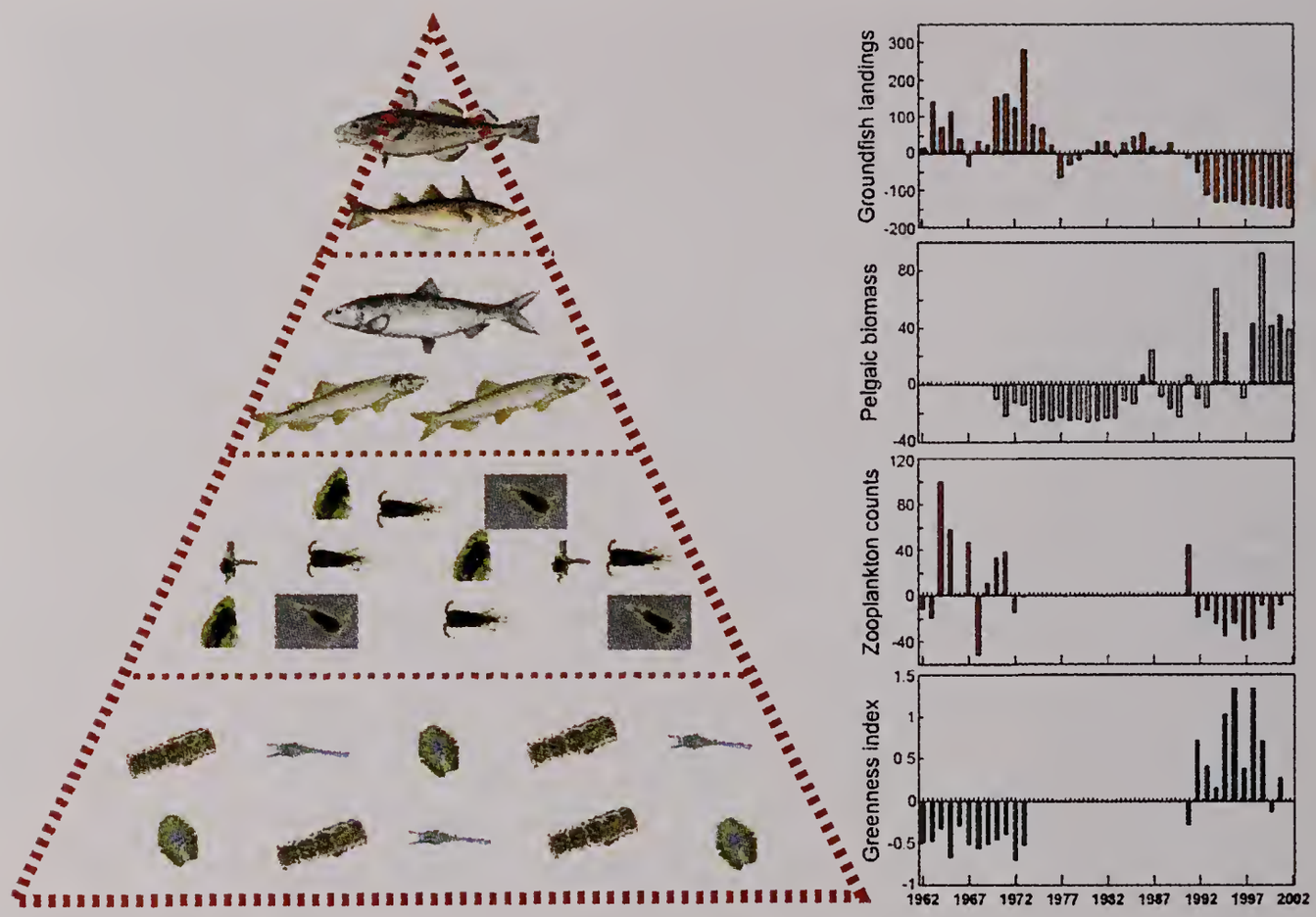

Fig 3 Pictorial representation of a trophic level cascade starting at the top with groundfish, then pelagics to zooplankton, and finally phytoplankton. Time series of annual anomalies of groundfish landings, pelagic biomass, zooplankton counts and CPR colour index, a measure of chlorophyll concentrations.

acid signature analysis (Iverson et al. 2004) and the results indicated that cod is occurring at only trace levels, i.e. less than 1%. Rather, the pelagic species capelin, sandlance and herring are the dominant prey in the diets of grey seals.

Currently, the invertebrate fisheries are extremely lucrative. Their rise in dominance is likely related to the decline in groundfish (their primary predators) as well as changes in the environmental conditions in the area. Invertebrate fisheries associated with lobster, snow crab and northern shrimp maintained and eventually increased revenues for the eastern Scotian Shelf despite the downturn in the traditional groundfish fishery. The temporal change in the average composition of the landings has been seen in several other fisheries systems and has been termed "fishing down the food web". It occurs when the average trophic level of the catch declines over time and the total catch decreases (Pauly et al. 1998). Both conditions are met on the Eastern Scotian Shelf, where the average trophic level (position in the food chain) of the catch of all species was relatively stable until the late 1980s (average of 3.6) and declined to a low of 2.7 in 2000. The total catch from the Eastern Scotian Shelf has also declined from a peak in the early 1970s to a low in the early 1990s (DFO 2003a). A lack of availability of groundfish has been created at the higher trophic levels of the ecosystem, and now the fishery is increasingly targeting species at lower levels in the food web.

Changes in ocean climate

Environmental variation has long been known to influence the distribution and abundance of marine organisms. Temperature is well recognized in terms of its effect on growth and maturation of most fish and invertebrate species. The timing of the onset of the spring phytoplankton bloom and its duration, known to be influenced by physical and chemical properties, can influence survival during the early life stages of a variety of species. Variability in circulation patterns can alter larval drift patterns and migration routes. The environment provides a variable setting within which species evolve and adapt. However, many environmental events are unpredictable, such as sudden intrusions of water masses, extreme storms, or long-term changes in temperature or salinity conditions.

During the past two decades, the temperature and salinity conditions of ESS waters have undergone significant changes. Of particular note is the presence of cold subsurface waters (below 50 m) in the northeastern region. Temperatures declined through the 1980s and dropped significantly to below normal (relative to the 1971-2000 mean of 1.73°C) in 1985 (Fig 4). They continued to decline, reaching a minimum in the early 1990s. Temperatures then increased slowly, eventually rising to above normal by the late 1990s. The almost 15-year duration of colder-than-usual temperatures is a significant feature in the over 50⁺-year record from the region. The early 1990s were generally the coldest years on record. The principal cause of these cold conditions appears to be along-shelf advection (flow) from both the Gulf of St. Lawrence and off southern Newfoundland, augmented by local atmospherically-induced cooling. Similar cold conditions were ob-

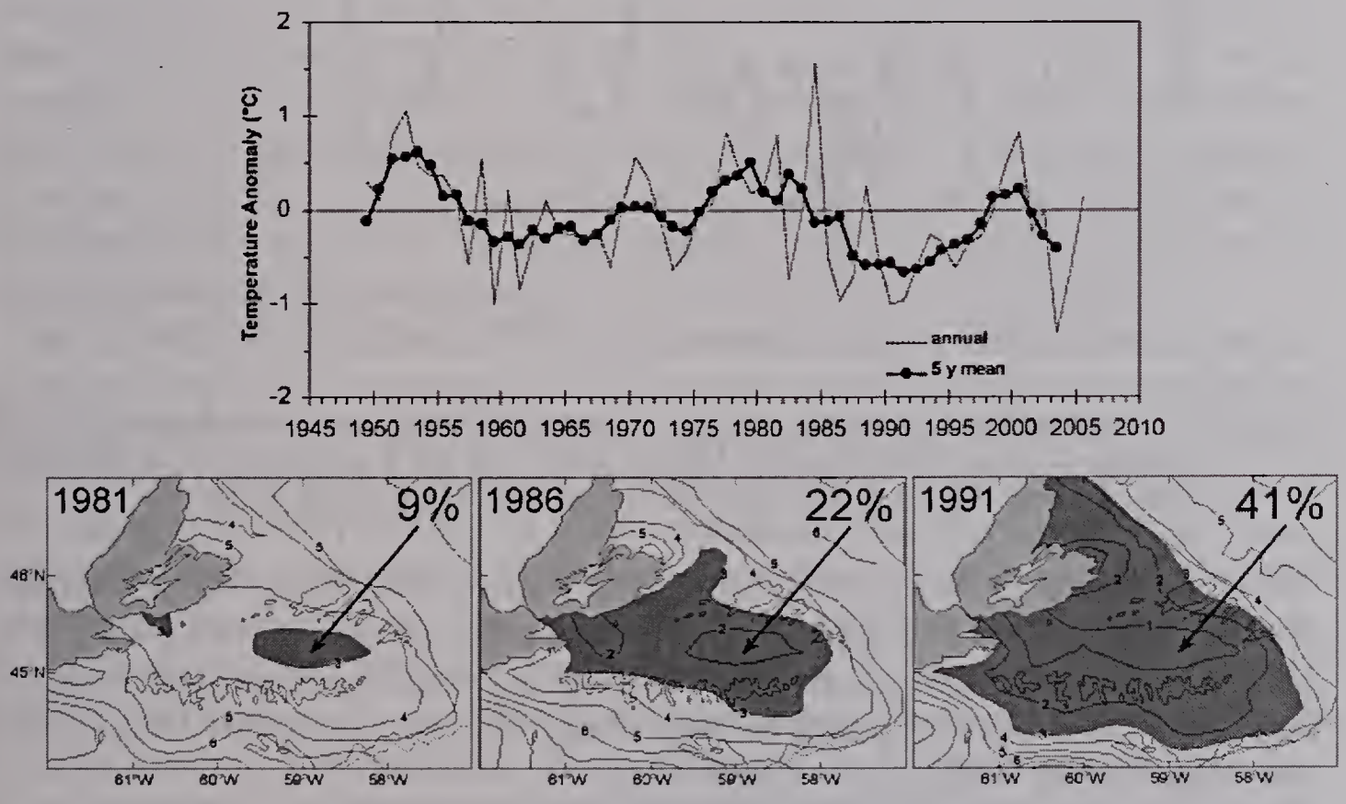

Fig 4 Time series of near bottom temperature at Misaine Bank. Contours of bottom temperatures in selected years (1981, 1986 and 1991) are shown below. The percentages indicate the amount of bottom area characterized by temperatures less than 3°C.

served in the nearshore regions of the Eastern Scotian Shelf but not in the southwestern region of Emerald Basin. There, the influence of the offshore Warm Slope Water moving into the Basin kept subsurface temperatures relatively warm throughout the 1980s and 1990s.

In addition to the subsurface changes, there have been important variations in the near surface waters. Foremost among these has been the increase in vertical density gradient, the difference between the density at 50 m and the surface (Fig 5). It increased to its highest level in the past 50 years over the top 50 m in the ESS during most of the 1990s. This was principally a result of record low salinities in the near-surface waters that appear to be advected onto the Shelf from the Grand Banks. Reduced storminess, as measured by the variability (standard deviation) in the wind stress at Sable Island may also have contributed to the increasing stratification during at least the first half of the 1990s through reduced vertical mixing. Freshwater discharge into the Gulf of St. Lawrence decreased during the 1990s and

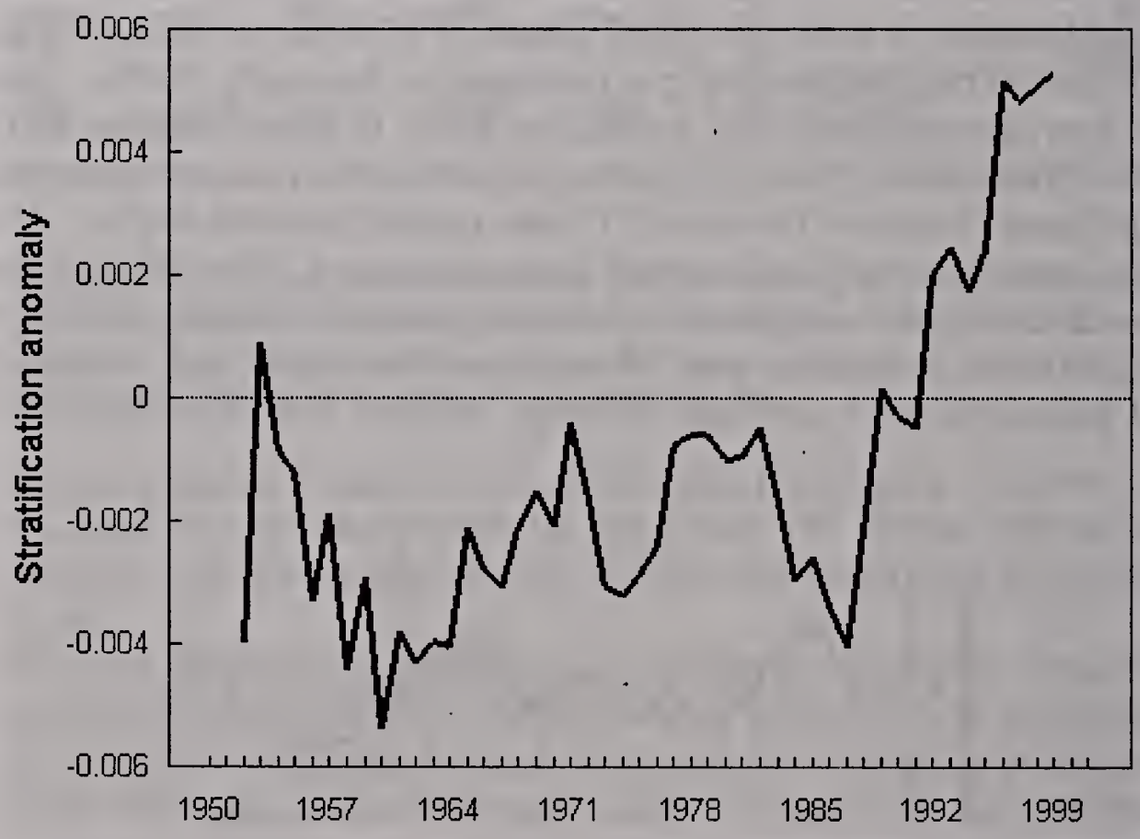

Fig 5 Time series (5 year running mean) of the density difference anomaly divided by 50 m between 50 m and the surface for Misaine Bank. The extreme increase in stratification since the late 1980s has not been witnessed before in the data series.

is not expected to have contributed to the lower salinities and increased stratification on the Scotian Shelf. Surface layer temperatures during the period of strong stratification were variable, although satellite data suggest that there were several years of high temperatures in the late 1990s, with the maximum in 1999.

Changes in the fish community

Profound changes in community composition and body size of groundfish have occurred during the past thirty years on the eastern Scotian Shelf.

The historical composition of the top five of ten species based on numerical abundance included: redfish, American plaice, silver hake, haddock and cod. This dominance structure has changed dramatically during the past decade and small pelagic species such as sand lance, capelin and herring are now dominant. Only silver hake and haddock have remained major groundfish species since the early 1980s, while cod, redfish, white hake, and thorny skate have decreased. In addition, 10- to 50-fold increases in the abundance of daubed shanny, turbot, snake blenny and sea poacher were evident in the most recent period relative to 1981-1992. The increasing species are all small-bodied, with the exception of turbot. In addition, temperature conditions appear to influence the occurrence of species new to the area, particularly when conditions remain persistently above or below normal. Several sub-Arctic species were first recorded during the anomalous cooling period that began in the mid-1980s; they include shorthorn sculpin, sea tadpole, Newfoundland eelpout, two horn sculpin, little grubby and checker eelpout. Overall, thirty new species have been captured since 1991, with the vast majority less than 35 cm long. Conversely, during the warm water conditions that began in the late 1970s several warm temperate/sub-tropical species were captured including beardfish, barracudina, batfish, greeneye, common wolfeel, deepwater flounder and snipe eel (Fig 6).

These temporal changes in fish species composition and abundance suggest that decreases in length and weight averaged across all groundfish species should be evident. The pattern of lowered average body weight was most evident during the 1990s with the largest reduction in the northeastern areas (Fig 7). A similar pattern was observed for fish lengths.

Declining average weight not only reflects increased abundance of small-bodied species, but also contracted size distribution of large-bodied species. For example, adult cod, haddock and pollock (age 5) are now much smaller on average compared to individuals from the 1970s and 1980s. Reductions in size at age are also found in silver hake. The trend of reduced size has occurred despite current low population levels, suggesting that a fundamental, population dynamic process (compensatory growth) is not working among these species.

As a direct consequence of the geometric scaling of numerous physiological, population-dynamic and life-history characteristics with organism size (allometry), there are numerous potential implications of these changes in average body size associated with the formerly large-bodied species of the Eastern Scotian Shelf. The most notable are: shorter generation times, increased natural mortality, increased population variability and decreased bioenergetic efficiencies. For example, direct estimation of natural mortality for cod and haddock was made possible by the closure of the directed fishery and showed levels 2-5 times higher than commonly assumed (DFO 2003b, Mohn & Simon 2002). Such changes do not necessarily translate to an unhealthy ecosystem but do indicate that it is functioning in a vastly different manner than it has in the past.

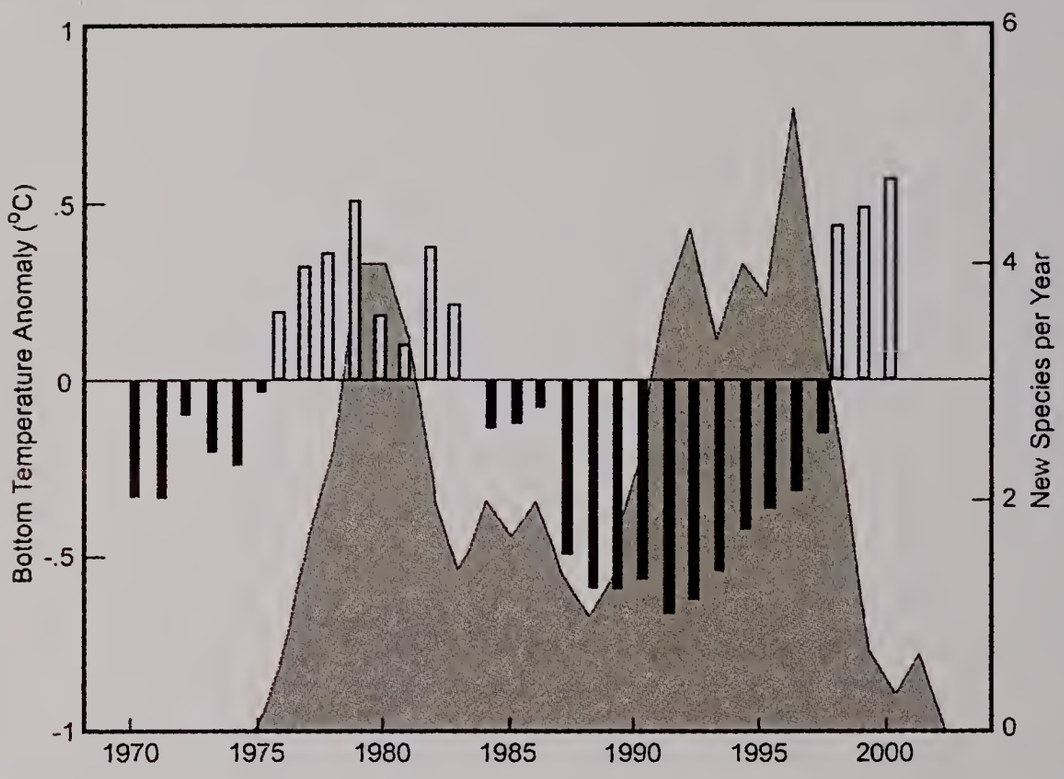

Fig 6 Time series of annual anomalies of bottom temperature at Misaine Bank and the occurrence of fish species new to the eastern Scotian Shelf each year. Note that each peak in the occurrence of species new to the area coincided with either sustained warm or cold bottom waters.

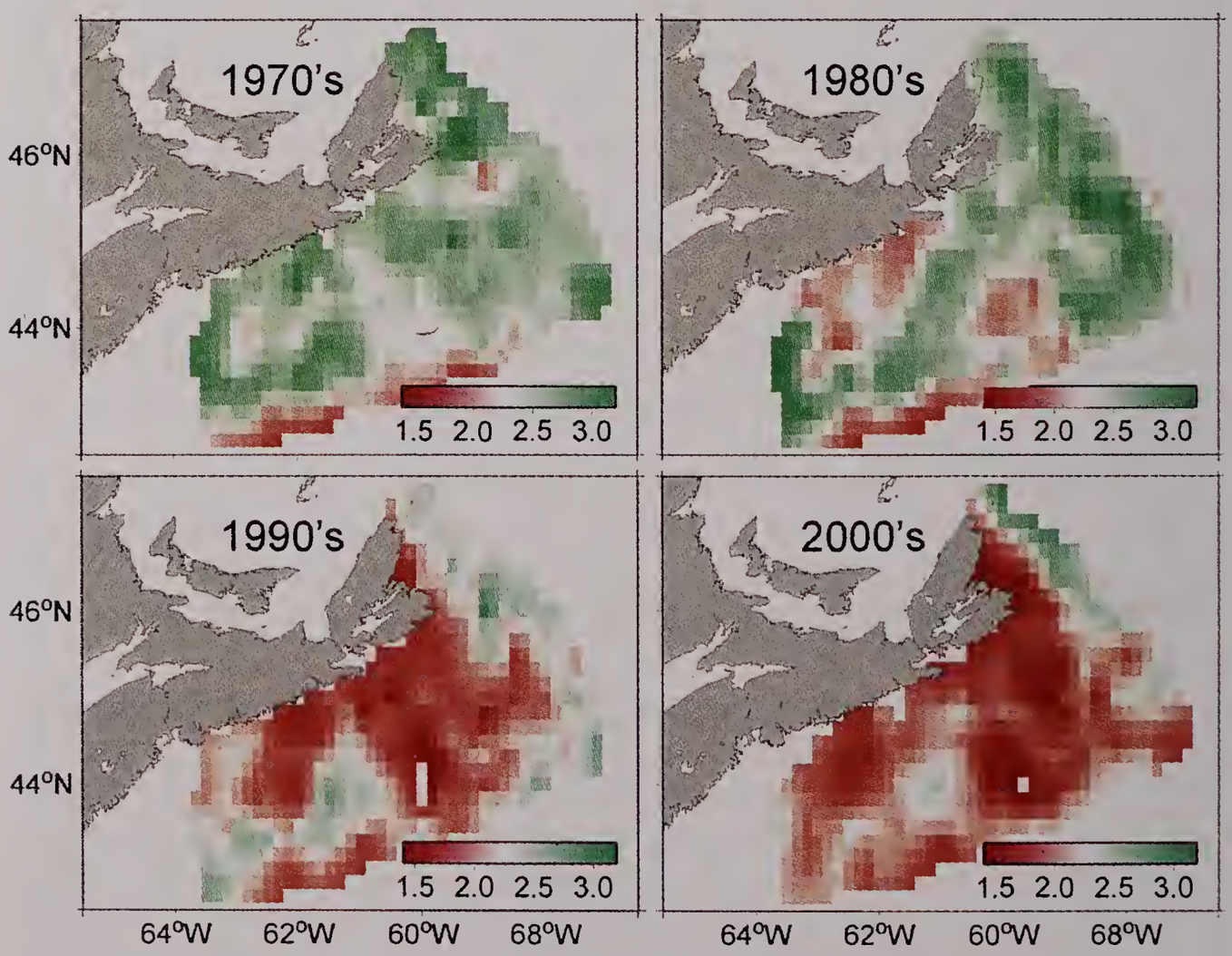

Fig 7 Spatial depiction of the average weight (kg) of groundfish on the Eastern Scotian Shelf for each of three decades (1970s, 1980s, 1990s) and for 2000-02. The trend towards lower average weight is quite striking.

FUTURE

What next in the short-term?

In the near future we plan on estimating system-level "structural" (biomass) and "functional" (metabolic rates, estimated from size-frequency distributions) changes of the fish-component of the entire Scotian Shelf ecosystem. Visualisations of these metrics in a spatial-temporal context and the relative discordance between structure and function will provide a direct estimate of system-level instability of the fish community. Another avenue of research that is being investigated is the use of size-spectral information in the context of "Self-Organized-Criticality" (Bak et al. 1989) to provide another means of evaluating system-level instability. Finally, comparative analyses between other systems that have not shown strong ecosystemic changes (e.g., locations where collapses of major fish stocks have not occurred) are planned to help further understand the causes of these large-scale changes in both ecological structure and function and the potential to identify early warning signs of such hysteresis.

What next in the long-term?

This comprehensive approach has revealed broad coherent patterns in ecosystem response that would have remained hidden had a single species approach been taken. While examination of single species will continue, the application of multi-species studies incorporating abiotic and human factors will grow. Effort is required to provide better representations of the non-biological driving forces so that they can be more readily incorporated into the fisheries analyses. Contemporaneous evaluations of the resource and environment by geographic area with acknowledgement of interactions between species and their environment is also required to advance the integration of abiotic forcing and ecosystem response. Dynamical connections between driving mechanisms and the fisheries response are needed; it will not be sufficient to connect an environmental variable to fisheries fluctuations simply through a statistical relationship.

It is our hope that comprehensive ecosystem reviews will be undertaken for other geographic areas and that once completed, periodic reviews will be conducted every 4 or 5 years, accompanied by minor annual updates. This will require continued financial commitment to long-term monitoring that is insensitive to short term social, economic and political volatility. In addition, it is important to note that the group that put together the State of the Eastern Scotia Shelf Ecosystem (DFO 2003) report was made up of specialists, some of whom are very highly specialized. Despite this, a valuable study has resulted; specialization alone does not preclude success in a broad study. The means must exist, however, to put the specialists together to address wide-ranging issues. Fortunately, it is not necessary to train generalists, but it helps to have at least some individuals on the team who are more catholic in their outlook.

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To provide an opportunity for students to have their work recognized by a scientific society and to have it considered for publication in a peer-reviewed scientific journal.

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PhD Student Microbiology and Immunology
Dalhousie University
for
"Clear as mud: the type I/type II model for death receptor-induced apoptosis"

The Graduate Student Special Prize for High Merit was awarded to:
Jane E. Tougas
Masters Student Computer Science
Dalhousie University
for
"A comparison of methods for modifying the partial singular value decomposition in latent semantic indexing"

The Undergraduate Student Prize in the Life Sciences was awarded to:
Mark Wall
BSc Student Chemistry
University College of Cape Breton
for
"Growth and phenyalanine ammonia lyase activity of *Rhodotorula glutinis:* optimization of conditions for the synthesis of L-phenylalanine"

The Undergraduate Student Prize in the Physical Sciences was awarded to:
Jackie Glister
BSc Student Physics
Saint Mary's University
for
"Design study of novel light geometry for scintillation counters"

The Scientific Writing Prize was awarded to:
Jennifer Paterson
School of Journalism
University of King's College
for
"Rational drug design: a window into the ambitious quest of a neurologist and chemist"

PROC. N.S. INST. SCI. (2006)
Volume 43, Part 2, pp. 201-209

2005 NSIS Graduate Student Prize Winning Paper

CLEAR AS MUD: THE TYPE I/TYPE II MODEL FOR DEATH RECEPTOR-INDUCED APOPTOSIS

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Apoptosis is a highly organized form of cell death that plays an important regulatory role in many biological processes. The relationship between the two classical signalling pathways of apoptosis, the "death receptor" and "mitochondrial" pathways, was only vaguely appreciated until 1998, when death receptor pathway-mediated activation of the mitochondrial pathway was clearly demonstrated for the first time. The "type I/type II" model of death receptor-mediated apoptosis was proposed and subsequently adopted for use in categorizing cells according to the involvement of the mitochondrion during death receptor-induced apoptosis. Since that time, however, different interpretations of the type I/type II cell definition have appeared in the literature and, consequently, the meaning of type I and type II cells has become less clear.

L'apoptose est une forme de mort cellulaire très structurée qui joue un rôle important de régulation dans un grand nombre de processus biologiques. La relation entre les deux voies de signalisation traditionnelles de l'apoptose, la voie des « récepteurs de mort » et la voie mitochondriale, n'était connue que vaguement avant 1998, l'année où l'activation de la voie mitochondriale par l'intermédiaire de la voie des récepteurs de mort a été clairement démontrée pour la première fois. Le modèle « type I / type II » d'apoptose par l'intermédiaire des récepteurs de mort a été proposé puis adopté aux fins de catégorisation des cellules en fonction de la participation des mitochondries à cette apoptose. Depuis, différentes interprétations ont toutefois été formulées dans des ouvrages scientifiques quant à la définition des cellules de type I et de type II et, par conséquent, la signification de « cellules de type I » et de « cellules de type II » est devenue moins évidente.

INTRODUCTION

There are several different mechanisms by which a cell can die (Fiers et al. 1999). "Necrosis" is the familiar type of cell death often caused by injury or disease, and effectively refers to the bursting of a cell. The release of lytic enzymes from inside the dead cell can cause further tissue damage and activate non-specific immune responses, resulting in painful inflammation. Conversely, "programmed cell death" is regulated at the molecular level and does not cause the contents of dying cells to be exposed. Instead,

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the cell's deoxyribonucleic acid (DNA)[1] is cleaved into fragments and the contents of the cell are packaged into small membrane-bound vesicles that are engulfed and removed by specialized immune cells, phagocytes, without causing any inflammatory reactions. The morphological features of programmed cell death, such as DNA fragmentation and the production of small membrane-bound vesicles, are collectively referred to as "apoptosis." This term is Greek in origin and describes petals falling from a flower, in reference to the membrane-bound vesicles that are produced from a dying cell. The terms "apoptosis" and "programmed cell death" are used interchangeably in the literature; thus, for clarity "apoptosis" will be used in place of "programmed cell death" for the remainder of this essay.

The two classical pathways of apoptosis are the death receptor pathway and the mitochondrial pathway. The death receptor pathway is initiated by aggregation of so-called death receptors (e.g., Fas, tumor necrosis factor (TNF) receptors, and TNF-related apoptosis-inducing ligand (TRAIL) receptors) present on the cell surface. Death receptors are transmembrane proteins that belong to the TNF/nerve growth factor superfamily of cell surface receptors, of which Fas is one of the most thoroughly studied. The cytoplasmic tails of these receptors contain a specialized amino acid sequence that allows them to initiate apoptosis (Fulda & Debatin 2004). A number of stimuli can trigger receptor aggregation, including natural receptor ligands, receptor-specific antibodies (Scaffidi et al. 1998), ultraviolet irradiation (Aragane et al. 1998), and certain cytotoxic compounds (Bush et al. 2001). The mitochondrial pathway can be initiated by intracellular stimuli, such as oxidative stress or DNA damage. These two pathways eventually converge and cells dying via either pathway are morphologically identical. Because apoptosis is the mechanism by which chemotherapeutic drugs and radiotherapy eradicate human cancer cells, and some human cancer cells develop mechanisms to avoid apoptosis, a better understanding of apoptosis may lead to strategies that increase the effectiveness of cancer treatments.

Apoptosis research from the last several years has revealed that, although mutually exclusive in many situations, the death receptor and mitochondrial pathways of apoptosis are intimately linked. Specifically, death receptor signalling can inefficiently induce the death receptor pathway such that it requires amplification, which is achieved by activation of the mitochondrial pathway. Scaffidi et al. (1998) identified two cell types: those that succumb to death receptor-induced apoptosis independently of the mitochondrion (type I cells), and those that require signal amplification (type II cells) following death receptor aggregation. With this model, cells can be catego-

[1] The abbreviations used are: Apaf-1, apoptosis protease-activating factor 1; Bax, Bcl-2-associated protein X; Bcl-2, B cell lymphoma-2 gene; Bcl-X_L, long form of Bcl-X; Bid, BH-3 interacting DD protein; caspase, cysteine aspartate protease; DISC, death-inducing signalling complex; DNA, deoxyribonucleic acid; FADD, Fas-associated death domain; Fas, fibroblast-associated; FasL, Fas ligand; PKR, protein kinase R; TNF, tumor necrosis factor; TRAIL, TNF-related apoptosis-inducing ligand; tBid, truncated form of Bid

rized according to the pathway(s) of apoptosis induced by death receptor signalling. Unfortunately, in recent years the definition of type I and type II cells has been manipulated to the point of ambiguity. The recent apoptosis literature, highlighting the different interpretations and consequent distortions of the type I/type II cell model, is used in the following discussion to clarify the issues and make the definition more understandable. A clearer understanding of the implications for the type I and type II phenotype in the responsiveness of cancer cells to various apoptogenic anti-cancer therapies may lead to more effective treatment of cancer in the future.

TYPE I AND TYPE II CELLS

Caspases are proteolytic enzymes that play a major role in apoptosis. The name "caspase" is derived from cysteine aspartate protease, because caspases cleave substrates that possess cysteine-aspartate motifs. These enzymes are normally present in the cell in the inactive "procaspase" form, and are activated by autoproteolytic cleavage or cleavage by other caspases. When the mitochondrial apoptosis pathway is activated, pores form in the mitochondrial membrane. Pore formation is regulated by the Bcl-2 (B cell lymphoma-2 gene) protein family. Pro-apoptotic members of this family, such as Bax (Bcl-2-associated protein X), are thought to oligomerize and create these pores. Conversely, pro-survival Bcl-2 protein family members, such as Bcl-x_L (long form of Bcl-X) and Bcl-2 itself, protect against the action of proteins like Bax by binding to them, inhibiting oligomerization and subsequent pore formation. When present, these pores act as conduits through which cytochrome c is released from the mitochondrion. In the cytosol of the cell, cytochrome c binds to apoptosis protease-activating factor 1 (Apaf-1), and together they activate procaspase-9. In turn, caspase-9 activates procaspase-3, and caspase-3 mediates late apoptotic events such as DNA fragmentation (Liu et al. 1997). The death receptor pathway is initiated by aggregation of death receptors. Inside the cell, Fas-associated death domains (FADD) associate with the cytoplasmic tails of aggregated death receptors, and procaspase-8 associates with FADD. This complex of death receptor, FADD and procaspase-8 is referred to as the DISC, for death-inducing signalling complex. In the DISC, procaspase-8 is activated by autoproteolytic cleavage, and active caspase-8 then activates procaspase-3.

Scaffidi et al. (1998) examined death receptor-mediated apoptosis, induced by an anti-Fas antibody, in several different cell lines. In this study, two distinct death receptor pathways were identified: one involving rapid cleavage of caspase-8, and the other displaying delayed caspase-8 activation. It was subsequently determined that delay of caspase-8 activation occurs because activation of the mitochondrial pathway is required in order to amplify a weak death receptor signal. Activation of the mitochondrial pathway ultimately yields greater amounts of active caspase-8, enabling apoptosis to occur. From this study was born new terminology in the apoptosis litera-

ture. Type I cells were those that died following anti-Fas antibody treatment without involvement of the mitochondrion, whereas apoptosis in type II cells was mitochondrion-dependent (Fig 1). The molecular mechanism for

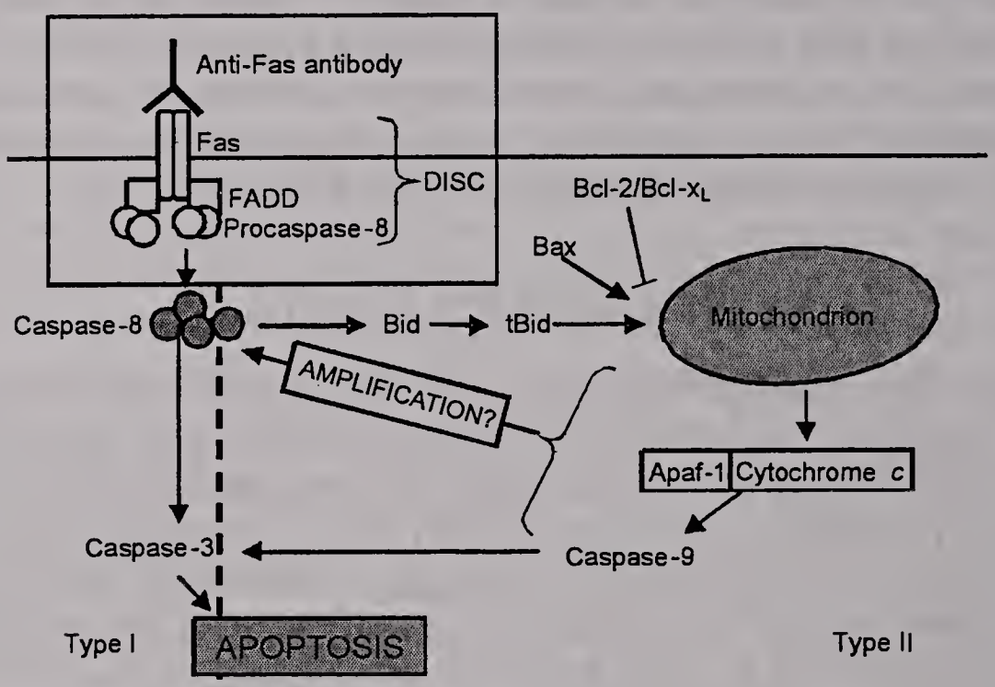

Fig 1 Anti-Fas antibody-induced apoptosis in type I and type II cells.
In type I cells, directly following anti-Fas antibody-induced aggregation of Fas, procaspase-8 is activated, yielding caspase-8, which activates procaspase-3. In type II cells, procaspase-3 is not immediately activated following Fas aggregation, due to insufficient generation of caspase-8. Instead, caspase-8 cleaves Bid, producing tBid, which activates the mitochondial pathway. Through an undetermined amplification mechanism, more caspase-8 is then generated and apoptosis ensues. Also shown are Apaf-1, cytochrome c, caspase-9 and Bcl-2 protein family members, which are involved in the mitochondrial apoptosis pathway.

activation of the mitochondrial pathway by death receptor-induced apoptosis was elucidated that same year. Luo et al. (1998) demonstrated that the mitochondrial pathway is triggered by the protein Bid (BH-3 interacting DD protein), and Li et al. (1998) showed that Bid is activated by caspase-8 in the death receptor pathway for type II cells. Caspase-8 cleaves Bid, yielding truncated Bid (tBid), which acts on the mitochondrion (Fig 1).

Unfortunately, one key aspect of this signalling model was unknown at the time and remains cryptic even today. Although it is well established that activation of the mitochondrial pathway amplifies caspase-8 activation, the molecular interactions that govern this process have yet to be identified. Recently, it was shown that caspase-3 might participate in a mitochondrial amplification loop (von Haefen et al. 2003, Klöpfer et al. 2004). This was inferred from the observation that caspase-8 is activated after caspase-3 activation, and that inhibition of caspase-3 activity prevents activation of caspase-8. In these studies, however, the authors failed to demonstrate directly that caspase-3 activates caspase-8. The possibility therefore remains that caspase-3 simply participates in a pathway that leads to

caspase-8 activation. For example, caspase-3 can mediate protein kinase R (PKR) activation (Suen et al. 2003) and PKR has been shown to participate in activation of caspase-8 (Gil & Esteban 2000, Page et al. 2002). Taken together, these observations suggest that PKR might complete the mitochondrial amplification pathway by mediating caspase-3-dependent activation of caspase-8. Currently, however, the caspase-8 amplification step is only vaguely understood, and the importance of PKR in type II cell death receptor-induced apoptosis remains unexplored.

"TYPE I/TYPE II" IN THE LITERATURE

In 1999, the authors of the original type I/type II cell paper released a short article detailing several subsequent experiments that were performed in order to determine whether Fas ligand (FasL), the natural binding partner for Fas, induces apoptosis in the same fashion as anti-Fas antibodies (Schmitz et al. 1999). In response to anti-Fas antibodies and FasL, apoptosis appeared to be the same. In one experiment, the authors engineered their cells to overexpress pro-survival Bcl-2 protein family members and tested whether protection against FasL- and anti-Fas antibody-induced apoptosis was conferred on the genetically engineered cells. Indeed, overexpression of these pro-survival proteins did protect type II cells from FasL- and anti-Fas antibody-induced apoptosis, whereas a prototypic type I cell line remained vulnerable despite high Bcl-2 expression. The authors extended this observation to infer that such protection by pro-survival Bcl-2 protein family members is indicative of a type II cell. In addition, the authors suggested that a fundamental difference between type I and type II cells is that FADD recruitment to Fas is impaired in type II cells, which they demonstrated by visualizing the amount of FADD associated with Fas in either type of cell. The following year, a report was released that challenged the use of Bcl-2-conferred protection against death receptor-induced apoptosis for determining cell type, highlighting instead the importance of the nature of the apoptosis-inducing stimulus itself (Huang et al. 2000). Here the authors indicated that Bcl-2 family members provide no protection against apoptosis triggered by FasL in type II cells, and also that FADD-related differences are not distinct between the two cell types. This appears to be the first report questioning the validity of the type I/type II model, specifically suggesting that beyond cell and tissue type, the apoptosis-inducing stimulus might also dictate the nature of death receptor-induced apoptosis.

In hindsight, this original criticism of the type I/type II model, specifically concerning the importance of the nature of the death-inducing stimulus, now seems prophetic. In recent years numerous reports have surfaced where the type I/type II label has been liberally applied to cells as a result of apoptosis studies involving many different apoptosis-inducing stimuli. One that stands out is a report by members of the group that first described the type I/type II model. Here, however, 25 cell lines were categorized as type I or type II based on their response to soluble FasL, rather than anti-Fas

antibodies (Algeciras-Schmnich et al. 2003), in spite of the known differences between FasL- and anti-Fas antibody-induced apoptosis (Huang et al. 2000). Unfortunately, no studies on anti-Fas antibody-induced apoptosis in these same 25 cell lines have yet been performed to support or refute their findings.

Although the term "death receptor" refers to Fas as well as TRAIL and TNF receptors alike, the type I/type II model for death receptor-induced apoptosis was based only on Fas-mediated apoptosis. Since different Fas stimuli (e.g. anti-Fas antibodies vs. FasL) have different effects on apoptosis even in the same cell type (Huang et al. 2000), it is not surprising that a recent study on TRAIL receptor-mediated apoptosis was not consistent with the type I/type II model (Rudner et al. 2005). Here, the authors observed that the hallmark protective effect of Bcl-2 against death receptor-induced apoptosis in type II cells was limited only to lower doses of the death-inducing stimulus, which in this study was TRAIL. Although not based on anti-Fas antibody-induced apoptosis, this study was useful in demonstrating that in addition to the nature of the apoptosis-inducing stimulus, the dose of that stimulus may also dictate the way in which apoptosis occurs. To their credit, the authors refer to "type I/type II reactions", and not just "type I/type II cells" in this report. It is not immediately obvious whether this study truly contributes to the "type I/type II" field of apoptosis research. Here, the prototypic Fas receptor was not activated for induction of apoptosis. Instead, the type I/type II model was applied to TRAIL-mediated apoptosis, perhaps because Fas and TRAIL are both death receptors. However, multiple different TRAIL receptors can trigger cell death (Hoskin 2000), and may each transduce distinct apoptosis signals. Also, recruitment of FADD and caspase-8 for DISC formation is not common to all death receptors (Harper et al. 2003). It would therefore be unwise to assume that all death receptor family members are equal in terms of the apoptosis signals they transduce.

Certain cytotoxic drugs can induce the Fas apoptosis pathway. Consequently, apoptosis induced by these drugs has been studied in the context of the type I/type II model. In most of these studies, DISC formation and the involvement of caspases is clearly established. However, since anti-Fas antibodies are not the apoptosis-inducing stimulus, should the drug-induced form of Fas activation be an acceptable application of the type I/type II model? One example where the type I/type II model might apply to drug-induced apoptosis is that of ceramide. Originally, Fas-induced apoptosis was shown to involve intracellular production of the lipid, ceramide. Some believe that ceramide production is an essential step in death receptor-induced apoptosis, although this claim remains somewhat controversial. It has been observed that ceramide induces apoptosis in type II Jurkat T leukemia cells via a signalling pathway analogous to that of Fas-mediated apoptosis (Caricchio et al. 2002). Subsequently, sensitivity to ceramide has appeared in the literature as a criterion for type II cells (Barnhart et al. 2003). When ceramide-induced apoptosis in Jurkat cells was studied, normal cells as well as those rendered resistant to killing by FasL were

examined (Caricchio et al. 2002). Ceramide sensitivity was evident in the former cell type, while in the latter resistance to FasL killing also conferred protection against ceramide-induced apoptosis. This report provides evidence that ceramide is a critical signalling intermediate in the Fas pathway of cell death. However, FasL- and anti-Fas antibody-induced cell death are not equivalent (Huang et al. 2000), and the type I/type II model is based on anti-Fas antibody-induced apoptosis (Scaffidi et al. 1998). How relevant to the type I/type II model is a study on FasL-resistant cells? A further study using anti-Fas antibody-resistant cells would settle this issue, and more accurately determine how the type I/type II model might apply to ceramide-induced apoptosis.

Other stimuli also induce Fas-dependent apoptosis, such as ultraviolet light, which can induce aggregation of Fas (Aragane et al. 1998). Curcumin, a component of the spice turmeric, has also been shown to induce Fas aggregation, as well as caspase-8-dependent apoptosis (Bush et al. 2001), and both curcumin and ultraviolet light can induce apoptosis independently of FasL. Under these conditions Fas expression may be increased in response to the cytotoxic stimulus (Müller et al. 1998), and Fas aggregation might occur due to elevated numbers of Fas molecules on the cell. Still other drugs, like the anti-cancer drug doxorubicin, cause Fas-dependent apoptosis by inducing expression of FasL (Friesen et al. 1996). In one report, doxorubicin was used as the apoptosis-inducing stimulus and apoptosis was studied in the context of type I/type II cells (Fulda et al. 2001). Certain molecular events in doxorubicin-induced apoptosis agreed with the type I/type II model; DISC formation was far greater in type I cells than in type II cells, and apoptosis in type II cells was dependent on the mitochondrial pathway. In contrast, the authors found that doxorubicin induces Bid cleavage in both type I and type II cells, suggesting that the type I/type II model should not extend to drug-induced apoptosis. Indeed, it may be naïve to assume that a drug would have no other effect on the cell, beyond Fas aggregation, that could affect apoptosis.

SUMMARY

The type I/type II model for death receptor-induced apoptosis has been a valuable tool for understanding apoptosis under very specific conditions, and may someday help researchers predict chemosensitivity or resistance in tumours. Unfortunately, the type I/type II model has been altered and applied to irrelevant experimental systems by several research groups. Labelling a cell as type I or type II should be carefully considered, and carried out only after meticulous examination of anti-Fas antibody-induced apoptosis; however, even this rule may be too vague. Evidence suggests that the amount of anti-Fas antibody used to induce apoptosis may inherently alter the apoptotic response. Unfortunately, in the original type I/type II report a single agonistic anti-Fas antibody clone was used, and, in the majority of experiments, only at a single dose (1 g/ml) (Scaffidi et al. 1998). In only

one experiment did the authors examine the effects of different doses of the anti-Fas antibody on type I/type II cell apoptosis, and the concentration of that antibody never exceeded 1 g/ml.

Fortunately, the type I/type II model is slowly evolving within the literature. Researchers are beginning to use terms like "type I/type II pathway", "type I/type II apoptosis" and "type I/type II reactions" (Amanullah et al. 2002, Bond et al. 2002, Arechavaleta-Velasco et al. 2002, Rudner et al. 2005). Perhaps "type I and type II apoptosis" will someday be universally accepted, simply referring to caspase-8-mediated apoptosis that is independent of and dependent on the mitochondrion, respectively. Such a model of type I/type II apoptosis would be more versatile, as it could be applied in the context of any cell death stimulus. As yet, however, this area of apoptosis research remains controversial. Hopefully these issues will be resolved in coming years.

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A COMPARISON OF METHODS FOR MODIFYING THE PARTIAL SINGULAR VALUE DECOMPOSITION IN LATENT SEMANTIC INDEXING

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The tremendous size of the Internet and modern databases has made efficient searching and information retrieval (IR) important. Latent semantic indexing (LSI) is an IR method that represents a dataset as a term-document matrix. LSI uses a matrix factorization method known as the partial singular value decomposition (PSVD). Calculating the PSVD of a large term-document matrix is computationally expensive. In a rapidly expanding environment, a term-document matrix is altered often as new documents and terms are added. Recomputing the PSVD of the term-document matrix each time these slight alterations occur can be prohibitively expensive.

Folding-in is one method of adding new documents or terms to an LSI database; updating the PSVD of the existing LSI database is another. The folding-in method is computationally inexpensive, but may cause deterioration in the accuracy of the PSVD. The PSVD-updating method is computationally more expensive than the folding-in method, but better maintains the accuracy of the PSVD. Folding-up is a new method that combines folding-in and PSVD-updating. Folding-up is faster than either recomputing the PSVD or PSVD-updating, but avoids the degradation in the PSVD that can occur when the folding-in method is used on its own.

La taille incroyable d'Internet et des bases de données modernes a fait en sorte que la recherche efficace d'informations est maintenant importante. L'indexation par sémantique latente (ISL) est une méthode de recherche d'informations qui représente un jeu de données comme une matrice document-terme. L'ISL comprend l'utilisation d'une méthode de factorisation matricielle connue sous le nom de décomposition partielle en valeurs singulières (DPVS). Le calcul de la DPVS d'une grande matrice document-terme est coûteux sur le plan des calculs. Dans un environnement en expansion rapide, une matrice document-terme est souvent modifiée à mesure que de nouveaux documents et termes sont ajoutés. Le recalcul de la DPVS de la matrice document-terme chaque fois qu'une légère modification est apportée peut devenir très coûteux.

L'intégration (folding-in) est une méthode pour ajouter de nouveaux documents ou termes dans une base de donnée ISL, et la mise à jour de la DPVS de la base de données ISL existante en est une autre. La méthode d'intégration est peu coûteuse sur le plan des calculs, mais elle peut entraîner une perte d'exactitude de la DPVS. La méthode de mise à jour de la DPVS est plus coûteuse sur le plan des calculs, mais elle permet de mieux préserver l'exactitude de la DPVS. La méthode d'intégration et de mise à jour (folding-up) est une nouvelle méthode qui combine l'intégration et la mise à jour de la DPVS. Cette méthode est plus rapide que le recalcul ou la mise à jour de la DPVS, mais elle permet d'éviter la perte d'exactitude de la DPVS qui peut survenir quand seule la méthode d'intégration est utilisée.

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INTRODUCTION

The expansion of both the Internet and modern databases has sparked an increased interest in methods for the efficient retrieval of information. Latent semantic indexing (LSI) is an information retrieval (IR) method that relies heavily on methods from numerical linear algebra (NLA). LSI thus combines two very different, although equally interesting, fields of study.

The efficient retrieval of textual information is hampered by the fact that many words have more than one meaning (they are *polysemous*). When a polysemous word is used in a search query, irrelevant documents about the word's other meaning(s) may be retrieved. A further complication arises from the fact that many words have similar meanings (they are *synonymous*). When a word that has a synonym is used in a search query, relevant documents containing the synonym, but not the specific word used in the query, may be overlooked. LSI uses a matrix factorization method known as the partial singular value decomposition (PSVD) in an attempt to reduce the retrieval problems caused by polysemy and synonymy.

LSI uses a mathematical approach to examine a document collection as a whole and determine which documents contain many of the same words. The more words documents have in common, the more closely related they are considered to be. When a search query is made, documents containing the words used in the search are returned, but so are those that are closely related to these documents. This allows the retrieval of documents that do not contain all or even any of the words given in the search query (Berry & Browne 1999, Yu et al. 2002).

The mathematical approach LSI uses is known as the vector-space model (Berry & Browne, 1999, Berry et al. 1999, Salton & McGill 1983). This approach creates a *term-document matrix* in which there is a vector for each document, with as many entries as there are semantically significant terms in the documents. The term-document matrix is essentially a table of numbers with, as already noted, a column (vector) for each document, and a row for each term. This matrix is of size t x d, where t denotes the number of terms, and d the number of documents. Refer to this matrix as **A**, and to each entry as a_{ij} , where $1 \leq i \leq t$ and $1 \leq j \leq d$. Each entry indicates the presence or absence of a particular term in a particular document; this may be a weighted frequency that reflects the importance of each term in each document. Search queries are also represented as *t*-dimensional vectors. The query vectors are projected into the term-document matrix using the PSVD. The vectors of documents and queries with many terms in common will be close together in the vector space, whereas those with relatively few terms in common will be far apart. The cosine of the angle between two vectors is commonly used as a measure of the similarity of the vectors. The cosine of the angle between two vectors that are close together will be large, whereas the cosine of the angle between two vectors that are far apart will be smaller.

Problem and motivation

Even using the most advanced NLA methods, calculating the PSVD of a matrix is an extremely expensive computation. In LSI, most of the computation time is spent in calculating the PSVD (Berry et al. 1999, Berry et al. 1995). In a dynamic environment, such as the Internet, the term-document matrix is changed often as new documents and terms are added. Recalculating the PSVD of the matrix each time such changes occur can be prohibitively expensive. Traditionally, LSI uses a process known as folding-in to modify the PSVD. Unfortunately, folding-in results in a trade-off between efficiency and accuracy; although this method is much faster than recomputing the PSVD, it is also much less accurate. Updating the PSVD is a more recent approach (Zha & Simon 1999) that offers a compromise. Updating the PSVD is a slower process than folding-in (although it is much faster than recomputing), but unlike folding-in, it results in little or no loss of accuracy.

The purpose of this paper is to illustrate that updating the PSVD is more accurate than folding-in, and also to introduce a new method, *folding-up*, that is a combination of folding-in and updating the PSVD. Folding-up is an attractive option because it offers a significant improvement in computation time when compared to either recomputing or updating the PSVD, and yet it results in little or no loss of accuracy.

Background

In order to understand the PSVD, it is helpful to understand the singular value decomposition (SVD). The SVD is a matrix factorization that can be used to capture the salient features of a matrix. Given a matrix A of size t x d, its SVD is written as $A = U\Sigma V^T$, where U is a size tx t matrix, Σ is size t x d, and V is size d x d. U and V contain the left and right *singular vectors* of A respectively. When A is a term-document matrix, U represents the term vectors and V represents the document vectors. The matrix Σ has non-zero entries only on the diagonal. These diagonal entries, denoted σ_j for $j = 1, 2, ..., \min(m,n)$ and arranged in non-increasing order, are known as the singular values of matrix A. The number of non-zero singular values of a matrix is known as its *rank*, r (see Fig 1).

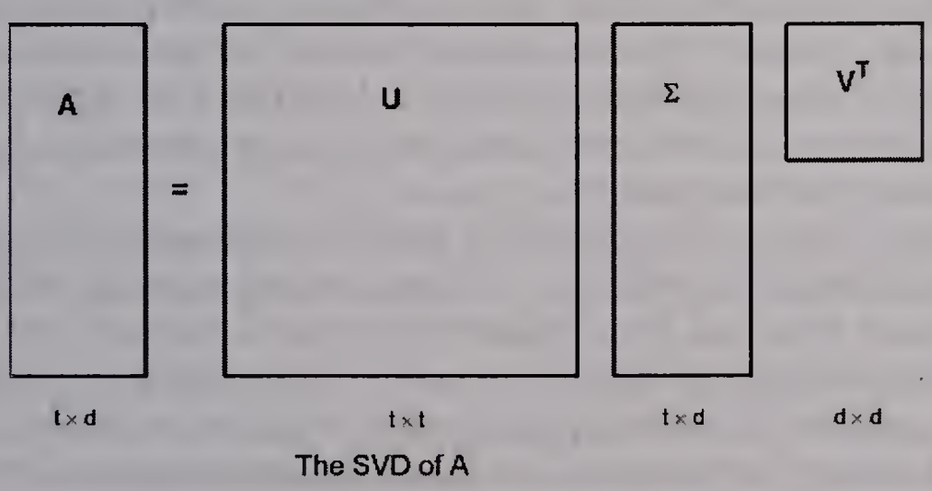

Fig 1 The singular value decomposition (SVD) of **A**.

An alternative way to represent the SVD is as the sum of r rank-one matrices $\mathbf{A} = \sum_{j=1}^{r} _j \mathbf{u}_j \mathbf{v}_j^T$, where $\mathbf{u}_j$ and $\mathbf{v}_j$ are the *jth* columns of matrices **U** and **V**, respectively. This representation of the SVD allows the formation of lower-rank approximations of **A**. Let matrices $\mathbf{U}_k$ and $\mathbf{V}_k$ be the first *k* columns of **U** and **V** respectively, and let matrix Σ_k be the leading submatrix of Σ with *k* rows and *k* columns. $\mathbf{A}_k = \mathbf{U}_k \Sigma_k \mathbf{V}_k^T$ is a lower-rank approximation of **A**, where $0 \leq \mathbf{k} < \mathrm{r}$. This is the partial SVD (PSVD) of **A**. This approximation can be used to reduce the dimension of the term-document matrix, while eliciting the underlying structure of the data. In LSI, the effect of this dimensional reduction on the data is a muting of the noise caused by synonymy and an enhancing of the latent patterns that indicate semantically similar terms. This means that $\mathbf{A}_k$ can actually be a better representation of the data than the original term-document matrix. The number of terms to keep in the reduced term-document matrix is still open to debate, but experiments indicate that values of *k* between 100 and 300 give the best results (Berry et al. 1995). This tremendous dimensional reduction, given the potentially huge size of the term-document matrix, demonstrates the power of the SVD as a method of data compression (see Fig 2).

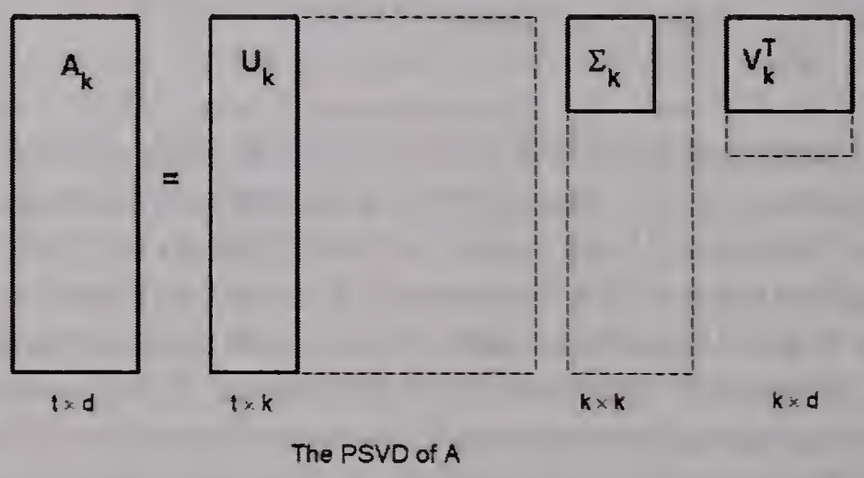

Fig 2 The partial singular value decomposition (PSVD) of **A**.

METHODS

Let $\mathbf{A} = \mathbf{U}_k \Sigma_k \mathbf{V}_k^T$ be the PSVD of the term-document matrix of size *t x d*, where *t* is the number of terms, *d* is the number of documents, and k is the number of dimensions used in the PSVD. Let **D** be the *t x p* term-document matrix containing the document vectors to be appended to **A**, where *p* is the number of new documents.

The folding-in process projects **D** into the *k*-dimensional space with a matrix multiplication: $\mathbf{D}_k = \mathbf{D}^T \mathbf{U}_k \Sigma_k^{-1}$ The *p x k* projection $\mathbf{D}_k$ is then folded-in to the existing PSVD of **A** by appending it to the bottom of $\mathbf{V}_k$. This gives the modified matrix$\hat{\mathbf{V}}_k$ of size (d + p) x *k*. It is important to note that $\mathbf{U}_k$ and Σ_k are not modified in any way with this method. As more and more documents are folded-in, the term-document representation of the document collection, $\mathbf{U}_k \Sigma_k \hat{\mathbf{V}}_k$, becomes less and less accurate, because $\mathbf{U}_k$ and Σ_k are

not being modified to reflect the addition of the new documents. Folding-in terms follows a similar process.

Updating the PSVD when the term-document matrix changes is a more complicated process than folding-in. Unlike folding-in, which modifies only the matrix Vk, updating modifies each of the matrices $\mathbf{U}_k$, Σ_k, and $\mathbf{V}_k$. The end result (in the absence of rounding off errors) is the exact PSVD of the modified term-document matrix, without the expense of recomputing it from scratch. Although this is computationally more expensive than folding-in, it provides a more accurate representation of the modified document collection. Updating terms rather than documents is done in a similar manner.

Folding-up is new hybrid method that uses a combination of folding-in and updating to modify the PSVD of the term-document matrix when documents (or terms) are added. The idea is to begin by folding-in documents, but then discard the changes made by folding-in, and updating before the accuracy of the representation degrades significantly. The process has the merit of saving the document vectors that are being folded-in between updates; it repays this cost with a saving in computation time, coupled with the precision advantages of updating. If no updates have been made, the current term-document matrix is the initial matrix, otherwise it is the last updated term-document matrix. Once the number of documents that have been folded-in reaches a pre-selected percentage of the current term-document matrix, the vectors that have been appended to Vk during folding-in are discarded. The PSVD is then updated to reflect the addition of all of the document vectors that have been folded-in since the last update. These document vectors are then discarded. The process then continues, folding-in until the next update.

Experiments.

The experiments are run using *Matlab* Release 13 on an Ultra3 SunFire V880 (Solaris 8 operating system). The MEDLINE text collection (Cornell SMART System [ftp://cs.cornell.edu/pub/smart]) containing 1033 documents and 30 queries is used. Removing semantically insignificant terms gives a term-document matrix A_{med} of size 5735 _ 1033. The measure of similarity is the cosine of the angle between query and document vectors. For each example, the term-document matrix is incrementally updated with document vectors until its column space has approximately doubled. The average precision for the methods used in each example are compared. In each case, the average precision for each of the queries at 11 standard recall levels (0%, 10%, ···, 100%) is averaged to produce the overall average precision at each increment of each experiment. For each method used, the average precision is plotted at each of these increments, starting with the initial term-document matrix. All PSVDs are computed using the *Matlab* function svds, with $k = 125$ for the MEDLINE collection, where k is the number of singular values and corresponding left and right singular vectors computed. The updating method is based on a method introduced by Zha and Simon (1999). For the sake of brevity, the experiments described use

only the document updating method. Note that similar results are produced using the term updating method.

RESULTS

Example 1

$\mathbf{A}_{med}$, size 5735 _ 1033, is partitioned such that the first 533 columns are used as the initial term-document matrix, and the remaining columns are added incrementally, in groups of size 10. The average precision is compared for four methods at each increment: recomputing the PSVD, folding-in, updating, and folding-up. For the folding-up method in this example, updates occur when the number of documents folded-in reaches approximately 8% of the size of the initial matrix for the first update, and of the updated matrix thereafter. As expected, Fig 3 shows that the average precision for

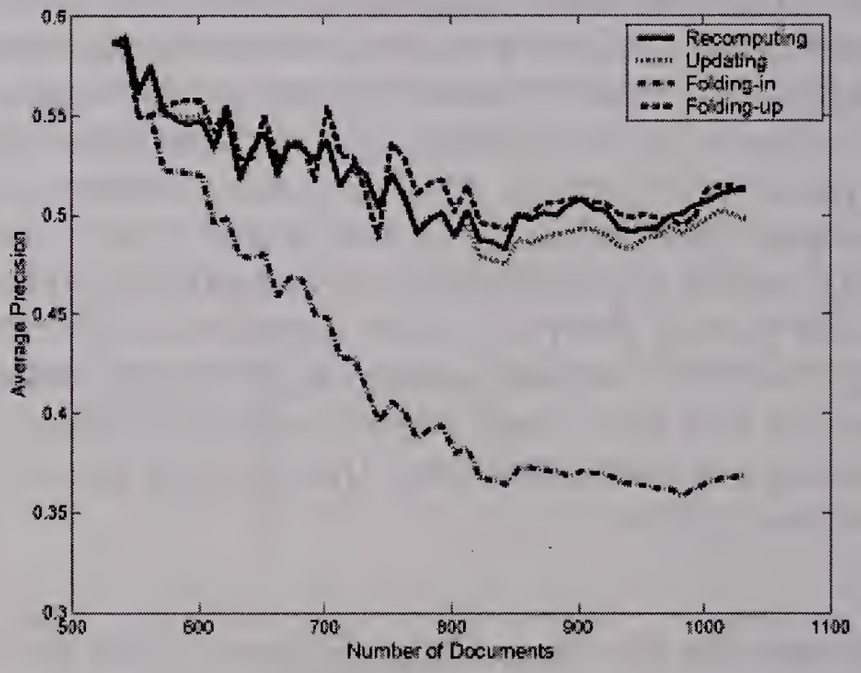

Fig 3 Comparison of the average precision of four methods for the MEDLINE collection, with 500 documents added in 50 groups of 10.

folding-in deteriorates rapidly. The average precision for updating does not begin to deteriorate until the initial matrix is more than one and a half times its original size, and the increments are less than 1.25% of the size of the matrix. Although the deterioration is slight, it does indicate that doing many updates that are very small relative to the size of the matrix may eventually have a negative affect on the average precision. However, the savings in computation time compared to recomputing, shown in Table 1, may more than compensate for this small deficiency; in this case, updating is more than 100 times faster than recomputing. Fig 3 shows that in this example folding-up actually outperforms the other methods for much of the graph, even though it is faster than either recomputing or just updating. See Table 1 for a comparison of CPU times.

Table 1 Comparison of total CPU times (seconds) for the MEDLINE collection with 500 documents added in groups of 10 and in groups of 25.

Method	CPU time	CPU time
	Increments of 10	Increments of 25
Recomputing	5001.60	2045.80
Updating	43.07	22.33
Folding-in	1.35	0.75
Folding-up	15.76	13.14

Example 2

$\mathbf{A}_{med}$, size 5735 _ 1033, is partitioned such that the first 533 columns are used as the initial term-document matrix, and the remaining columns are added incrementally, in groups of size 25. The average precision is compared for four methods at each increment: recomputing the PSVD, folding-in, updating, and folding-up. For the folding-up method in this example, updates

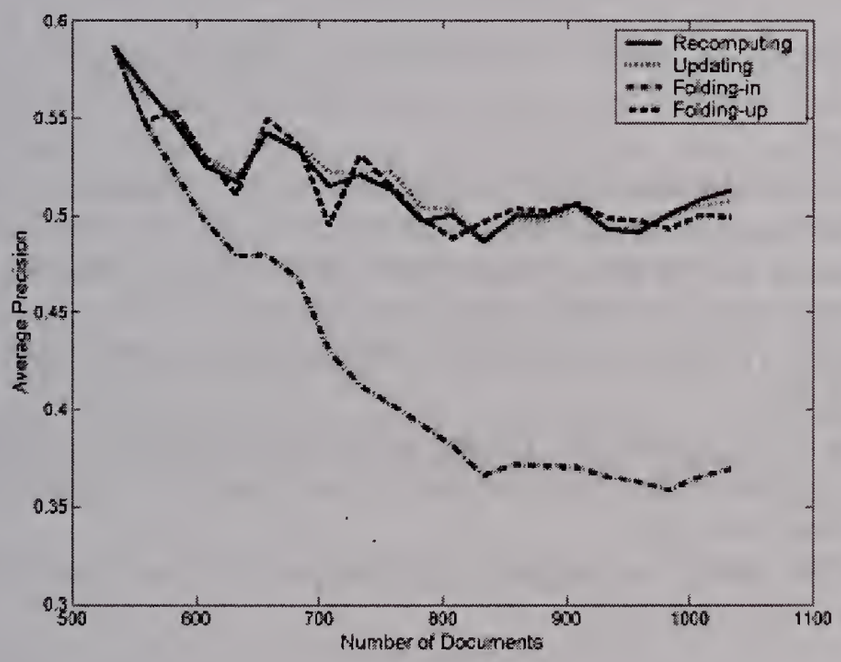

Fig 4 Comparison of the average precision of four methods for the MEDLINE collection, with 500 documents added in 20 groups of 25.

occur when the number of documents folded-in reaches approximately 14% of the size of the initial matrix for the first update, and of the updated matrix thereafter. As in Fig 3, Fig 4 shows that the average precision for folding-in deteriorates rapidly. The average precision for updating does not deteriorate, and is at times even slightly better than that for recomputing the PSVD. These results suggest that updating in larger increments, relative to the size of the matrix, can give optimal average precision. Folding-up again outperforms the other methods for some parts of the graph, while taking less computation time than either recomputing the PSVD or simply updating it. Table 1 gives a comparison of the CPU times for the methods.

CONCLUSIONS

LSI relies heavily on the PSVD of the term-document matrix representation of a document collection. Calculating the PSVD of large term document matrices is computationally expensive, therefore when documents (or terms) are added to an existing dataset, it is beneficial to update the existing PSVD to reflect these changes. Examples 1 and 2 illustrate that updating the PSVD of the term-document matrix each time changes are made to the document collection is not only much faster than recomputing the PSVD, but also gives better average precision than the traditional method of folding-in documents. Folding-up, a new method that is a combination of folding-in and updating, gives better average precision that folding-in, with less computation time than the updating method.

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GROWTH AND PHENYLALANINE AMMONIA LYASE ACTIVITY OF *Rhodotorula glutinis*: OPTIMIZATION OF CONDITIONS FOR THE SYNTHESIS OF L-PHENYLALANINE

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A procedure is described for the synthesis of L-phenylalanine from trans-cinnamic acid and ammonia utilizing the reverse reaction of phenylalanine ammonia lyase (PAL) from *Rhodotorula glutinis*. Optimal conditions determined for yeast growth and PAL production were pH 6, 1% inoculum, 30°C for 26-28 h. Optimization of conditions for maximal phenylalanine production included incubation time (16 -18 h), temperature (30°C), pH (9.0), selected concentrations of substrates: 0.1M *trans*-cinnamic acid and 4.0M NH_4OH and 0.1M Tris-HCl. Under these conditions about 85% conversion of substrate to product was obtained.

Nous décrivons une procédure pour la synthèse de L-phénylalanine à partir de l'acide cinnamique (trans-) et d'ammoniac au moyen de la réaction inverse de la phénylalanine ammonia lyase (PAL) de *Rhodotorula glutinis*. Les conditions optimales pour la croissance de la levure et la production de PAL étaient les suivantes : inoculum à 1 %, pH 6, milieu à 30°C, pendant 26 à 28 h. L'optimisation des conditions pour la production maximale de phénylalanine a nécessité une période d'incubation (de 16 à 18h), une température de 30°C, un pH de 9,0 et des concentrations données de substrats (0,1M d'acide cinnamique (*trans*-), 4,0M de NH_4OH et 0,1M de Tris-HCl). Dans ces conditions, environ 85 % du substrat a été converti en produit.

INTRODUCTION

The synthesis of L-Phe in optically pure form is an important reaction with clinical and industrial significance. This essential amino acid has several applications including its use as a dietary supplement in intravenous infusions (Trevan et al. 1987) and as a precursor of the artificial sweetener, aspartame (Oyama et al. 1987). Phenylalanine ammonia lyase (E.C.4.3.1.5 - PAL) catalyzes the spontaneous non-oxidative deamination of L-phenylalanine (L-Phe) to *trans*-cinnamic acid (t-CA) and ammonia (Koukol & Conn 1961).

This enzyme is widely distributed in higher plants (Koukol & Conn 1961, Jahnen & Hahlbrock 1988, Whetten & Sederoff 1992), some fungi (Kalghatgi

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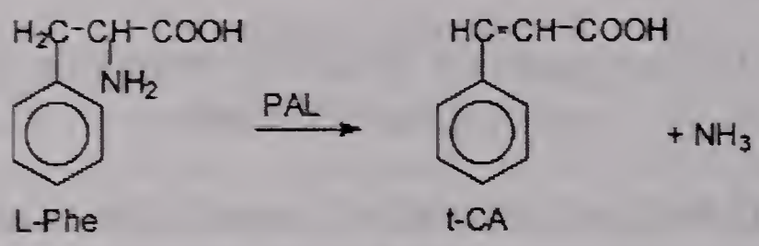

& Subba Rao 1975, Sikora & Marzluff 1982), yeasts (Ogata & Uchiyama 1967, Marusich et al. 1981, Orndorff et al. 1988) and in a single prokaryote, *Streptomyces* (Bezanson et al. 1970). It is absent from true bacteria and animal tissues.

PAL is the first and key enzyme of the phenyl propanoid sequence, a secondary metabolic pathway mainly involved in production of precursors of lignin in higher plants (Koukol & Conn 1961). In microorganisms, it has a catabolic role, allowing them to utilize L-Phe as a sole source of carbon (Marusich et al. 1981). Among the microorganisms, PAL occurs abundantly in yeast, especially in the red yeast basidiomycetes family, *Rhodotorula* (Marusich et al. 1981, Orndorff et al. 1988, Fritz et al. 1976). Other PAL producing yeasts are *Sporobolomyces roseus and Sporidiobolus pararoseus* (Ogata & Uchiyama 1967, Watanabe et al. 1992).

PAL is one of the few nonhydrolytic enzymes that have several commercial applications (Fritz et al. 1976, Watanabe et al. 1992, Ambrus et al. 1978, Hsia & Holtzmann 1973, Yamada et al. 1981, Evans et al. 1986a, b, Hamilton et al. 1985, Evans et al. 1987, Finkelman & Yang 1985, Nelson 1976). Commercially *Rhodotorula* yeast has been used exclusively for production of PAL because of its high PAL levels, nonfastidious requirements for growth and PAL synthesis (Orndorff et al. 1988, Evans et al. 1987). Purified *Rhodotorula* PAL is effective in the treatment of certain mouse neoplastic tumors (Fritz et al. 1976), the quantitative analysis of serum L-Phe in monitoring patients with phenylketonuria (Watanabe et al. 1992, Ambrus et al. 1978) and also in the preparation of low phenylalanine diets (Yamada et al. 1981).

Although L-Phe can be produced by chemical synthesis (Herbst & Shemin 1955), fermentation (Trevan et al.1987) or by enzymatic bioconversion of precursors (Yamada et al. 1981, Evans et al. 1986a, b, Hamilton et al. 1985, Evans et al. 1987, Finkelman & Yang 1985, Nelson 1976), the great demand for high yields of the optically pure L-isomer, has focused attention on the stereospecific production of L-Phe by biochemical methods. In addition, among the bioconversions, the use of PAL for the production of L-Phe has received maximum attention because of the low price of the raw feed stock, trans-cinnamic acid (t-CA) (Evans et al. 1986a, b, Hamilton et al. 1985, Evans et al. 1987, Finkelman & Yang 1985, Nelson 1976).

Our study has been conducted to extend the earlier work of Yamada et al. (1981) and Evans et al. (1987) on the synthesis of L-Phe from t-CA by PAL containing *Rhodotorula* yeast cells in an attempt to improve the yields of the product obtained by these authors.

MATERIALS AND METHODS

Microorganism

The yeast strain *Rhodotorula glutinis*, RE4607095D used in this study, procured from Oxoid Inc. (Nepean, Ontario) was maintained by weekly transfers on 3.0% agar plates and slants containing 1.0% peptone, 1.0% yeast extract, and 0.5% NaCl.

Chemicals

Yeast extract, peptone and agar were obtained from Oxoid Ltd. (Basingstoke, Hampshire, UK). L-Phe and Tris buffer were purchased from Fisher Scientific (Fairlawn, NJ, USA) and trans-cinnamic acid was obtained from Acros Organics (Morris Plains, NJ, USA). Commercially available reagents of highest analytical grade were used without further treatment.

Physiological manipulation of *Rhodotorula glutinis*

The effects of the following parameters on the growth and PAL activity of the *Rhodotorula glutinis* yeast were determined. (a) Medium composition 1) the minimal salts medium contained 1.0% $(NH_4)_2SO_4$, 0.5% KH_2PO_4, 0.05% $MgSO_4$, 0.001% $FeSO_4$, 0.001% $MnSO_4$, 0.001% NaCl, and 2.0% glucose or sorbitol in distilled water 2) the standard yeast extract medium contained 1.0% yeast extract, 1.0% peptone and 0.5% NaCl in distilled water; (b) pH (5-9); (c) size of inoculum (0.2-10%); (d) temperature during growth (30-42°C) and (e) time of harvest of cells (0-54 h) grown on an orbital shaker (160 rpm). The cells harvested by centrifugation at 7,500 x g for 15 min at room temperature were preserved at 0-2°C. Cell amounts used are reported on a dry weight basis.

PAL forward assay

The PAL forward activity of *Rhodotorula* yeast whole cells was monitored spectrophotometrically by the formation of t-CA from L-Phe at an absorbance of 290nm (Herbst & Shemin 1955, Evans et al. 1986b). The reaction mixture (5.0 mL) containing 50 mM Tris–HCl buffer, pH 8.5, 37.5 mM L-Phe and 10.0 mg of *R. glutinis* whole cells was incubated at 30°C for 10.0 min. The reaction was stopped by inactivating the enzyme with concentrated HCl and separating the cells by centrifugation at 7,500 x g for 15 min. The absorbance of the clear supernatant fluid was measured at 290 nm; the reaction mixture to which the substrate was added after termination of the reaction served as the blank. The enzyme activity is expressed in units; one unit of enzyme is defined as the amount required to transform 1 nmole of L-Phe/min/mg dry cells at room temperature.

PAL reversal assay

The reaction mixture consisted of 5 ml 0.1M Tris-HCl buffer, pH 9.0, containing 0.1M t-CA, 4.0M NH_4OH and 400 mg yeast whole cells. Samples containing boiled cells (100°C, 15 min.) served as controls. The reaction mixtures were incubated at 30°C with shaking (200 rpm). The reaction was

allowed to proceed overnight to obtain a measurable amount of the product, L-Phe. L-Phe was identified by paper chromatography; chromatograms were developed with 1-butanol: acetic acid: water (4:1:5, upper phase) for 2-3 h, air-dried for 30 min, and sprayed with 0.2% ninhydrin in ethanol. The chromatograms were heated at 105°C for 5 min. to reveal coloured spots, which were eluted with 0.5% $Cu(NO_3)_2$ in methanol for 20 min. in the dark, and the concentrations of eluted L-Phe was measured spectrophotometrically at 520 nm.

Data analysis

The values reported are the means of at least three separate determinations.

RESULTS

The optimal conditions for the growth and PAL activity of *Rhodotorula glutinis* are shown in Table 1. Under these conditions the PAL activity and biomass of *Rhodotorula glutinis* RE4607095D whole cells ranged from 17-19 units/mg dry cells and 3.5-4.0g dry cells/L in the standard yeast extract medium to 10-11 units/mg dry cells and 2.5g dry cells/L produced in minimal salts medium.

Table 1. Growth and PAL Activity - Optimal Conditions

Parameter	Range/Parameter Tested
Medium Composition	Minimal Salts or Yeast Extract Medium
pH	5.0 - 9.0
Size of Inoculum (%)	0.2 - 10.0
Temperature (°C)	15, 28, 30, 37, 42
Time (h)	0 - 54

L-phe formation during the PAL reversal reaction was proportional to the cell amounts up to 400mg. Maximal L-Phe accumulated after 16-18 hours of incubation (Fig 1).

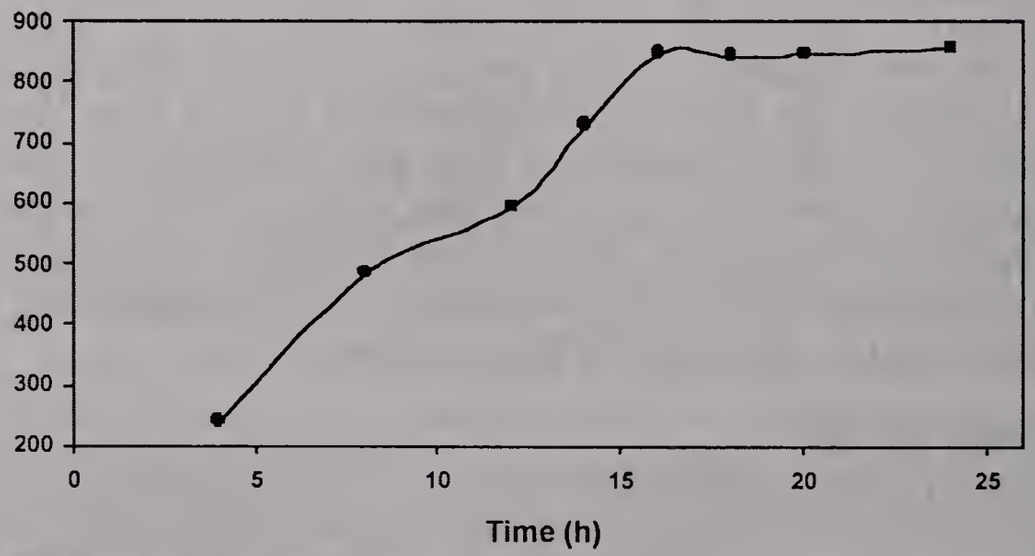

Fig 1 Effect of time on PAL reversal reaction.
Maximal L-Phe accumulated after 16-18 hours of incubation.

Optimal concentrations of t-CA and NH_4OH were 0.1-0.5M and 4.0-7.0M respectively. Higher concentrations of t-CA (>1.0M) were found to inhibit PAL reversal activity (Tables 2, 3).

Table 2. Effect of t-CA concentration on PAL

No.	Concentration of t-CA (M)	L-Phe (nmol h-1 mg-1 dry cells)
1	0.01	4
2	0.025	32
3	0.05	60
4	0.1	132
5	0.5	133
6	1	129
7	2	42

Table 3. Effect of NH_3 concentration of PAL

No.	Concentration of NH_3 (M)	L-Phe (L-Phe nmol h-1 mg-1 dry cells)
1	1.0	24
2	2.0	46
3	3.0	87
4	4.0	134
5	5.0	133
6	6.0	139
7	7.0	135

Among the various buffers (each at 0.1M concentration and pH 9.0) the yield of L-Phe in Tris-SO_4, borate, Tris-HCl, HEPES, and glycine was 105, 104, 133, 98, and 88 nmol/h/mg dry cells respectively. As 0.1M Tris-HCl buffer at pH 9.0 gave maximal conversions of t-CA to L-Phe it was used for all remaining studies (Fig 2).

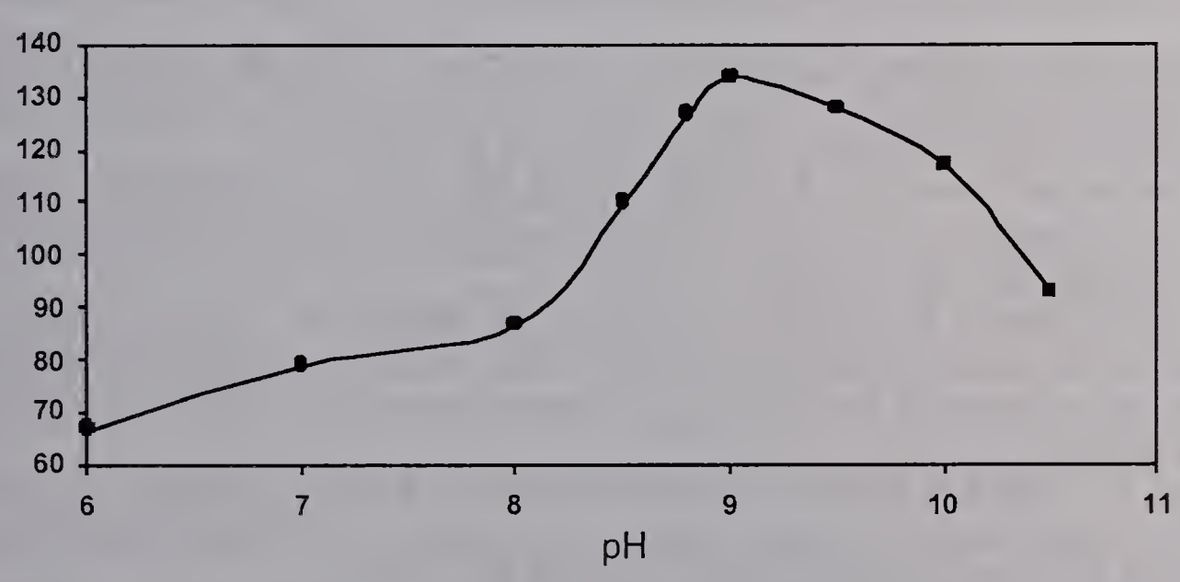

Fig 2 Effect of pH on PAL activity.
0.1M Tris-HCl buffer at pH 9.0 gave maximal conversion of t-CA to L-Phe.

The PAL reversal reaction carried out over a range of temperatures (25, 28, 30, 32, 37 and 42°C) gave yields of L-Phe at these temperatures of 87, 135, 138, 129, 98, and 73 nmol L-Phe/h/mg dry cells respectively. Under the optimized conditions for maximal L-Phe production (16 – 18 h, 30°C, 0.1M Tris-HCl, pH 9.0, 0.1M t-CA, 4.0M NH_4OH and 400mg dry cells *R. glutinis*) the reaction gave 850µmol L-Phe after 16 hours incubation at 30°C with shaking at 200rpm. This corresponds to an 85% substrate conversion.

DISCUSSION

The *Rhodotorula* PAL reversal reaction has been reported to be inhibited by its own substrate, t-CA (Evans et al. 1987). It is evident from table 2 that a higher concentration (>1.0M) of t-CA inhibited PAL reversal activity. Higher concentrations (>4.0M) of NH_3 (Table 3), however, did not make a significant difference with respect to inhibition of PAL reversal activity.

Genex Corporation has established a large-scale production process based on Rhodotorula cells for the synthesis of L-Phe (Finkelman & Yang 1985). Similarly, the authors of a US patent (Nelson et al. 1976) list a method of L-Phe production using *R. glutinis* PAL. Unfortunately, the details of the reaction, the conversion yield, and the concentration of L-Phe obtained are obscure. The product yield (85% substrate conversion) obtained in our study is appreciably higher than the 70% substrate conversion reported for L-Phe production by Yamada et al. (1981) and Evans et al. (1987). Our future studies are aimed at using L-Phe for the production of aspartame and the use of *R. glutinis* PAL in quantifying L-Phe in biological samples.

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2005 NSIS Undergraduate Student Prize Winning Paper in the Physical Sciences

DESIGN STUDY OF NOVEL LIGHT GUIDE GEOMETRY FOR SCINTILLATION COUNTERS

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Two scintillating panels (S1 and S2) have been used as triggers in the high resolution spectrometers in Hall A of the Thomas Jefferson National Accelerator Facility. New panels are to be installed in place of S1 and S2 and it was proposed that the currently used 90° twisted light guides be replaced by a new adiabatic S-shape design (2 or 3 strips). Using CERN's Guide7, Monte Carlo simulations were performed on four different light guide geometries: rectangular, standard fishtail, 2-strip S-shape and 3-strip S-shape. It was found that the two S-shape designs gave roughly 2x improvement on collection efficiency and 1.2-1.4x improvement on time resolution over simple designs (rectangular and fishtail). The 3-strip S-shape guide (90 pico-second time resolution and a 30% collection efficiency) was recommended for replacement of the twisted shape; actual experimental comparisons are also advised.

Deux panneaux scintillants (S1 et S2) servent de déclencheurs des spectromètres à haute résolution de la salle A de l'accélérateur national Thomas Jefferson. De nouveaux panneaux seront installés pour remplacer les S1 et S2, et on a proposé de remplacer les guides de lumière courbés de 90o utilisés actuellement par un nouveau modèle adiabatique en S (à deux ou trois bandes). Des simulations de Monte Carlo fondées sur le guide 7 du CERN ont été effectuées pour quatre géométries différentes de guides de lumière : rectangulaire, standard en « queue de poisson », en S à deux bandes et en S à trois bandes. Les deux modèles en S doubleraient l'efficacité de collecte et ils permettraient une résolution temporelle de 1,2 à 1,4 fois supérieure à celle des modèles simples (rectangulaire et en « queue de poisson »). Le guide en S à trois bandes (une résolution temporelle de 9 picosecondes et une efficacité de collecte de 30 %) est recommandé pour le remplacement des guides courbés. Des comparaisons expérimentales sont également conseillées.

INTRODUCTION

Our understanding of the subatomic world relies a great deal on a detector's ability to identify properly an incoming particle. Properties such as momentum, energy and charge are used to distinguish among a vast array of particles (hadrons, leptons, mesons, etc.). In order to minimize background readings, triggers are used to allow the particle identification and tracking detectors (Cherenkov and Vertical Drift Chambers for instance) to be informed that a reaction has occurred and incoming particles will be received shortly.

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A particle should be minimally affected by a trigger detector it passes through by retaining the majority of its energy and being deflected only narrowly from its path. Fast and accurate timing (high time resolution) is also essential to avoid recording of misleading background radiation by the other detectors.

A timing scintillation detector consists of a large-area, flat plastic scintillation panel connected to a cylindrical photomultiplier tube (PMT) by means of a light guide. The panels are thin to minimize energy absorption and path deflection. The light guide offers a means of joining the very different cross-sectional areas of the scintillator (rectangular) and PMT (circular). In Hall A of the Thomas Jefferson National Accelerator Facility (Jefferson Lab), two identical scintillation panels (S1 and S2) serve as primary triggers and contain 90° twisted light guides (Alcorn et al. 2004).

The S1 layer is to be replaced by the S1m layer and it has been proposed that a new light guide design, S-shape, replace the currently used twisted design. In order to demonstrate that the S-shape design is a worthy replacement, Monte Carlo simulations were performed using CERN's Guide7 (http://blast02.lns.mit.edu/software/oddsNends/guide7/).

BACKGROUND - LIGHT GUIDES

When a particle passes through an inorganic scintillator, photons are emitted through molecular excitation (Leo 1987). These photons are transported through the transparent material of the scintillator and guide by means of total internal reflection. For reflection to occur, the angle of incidence relative to normal must be greater than or equal to the critical angle,

$$\theta_{cr} = \sin^{-1}\left(\frac{1}{n}\right),$$

where the outer material is assumed to be air with refractive index equal to one.

Collection efficiency and time resolution are used as main criteria for determining light guide efficiency, indicating a minimum change of the output from a scintillator by the transmission of photons through the guide. Collection efficiency is the number of photons collected at the PMT per number created in the scintillator. A high collection efficiency allows the observation of smaller signals amidst background noise and/or allows the use of thinner scintillators. High time resolution means small variation in the time a generated pulse takes to reach a specified observation threshold, and is needed for accurate triggering.

Simple vs. complex light guides

Simple light guides consist of straight sides and/or gradual tapering. They are cost-effective since they require only a short time to design and build. Rectangular and standard fishtail geometric shapes are commonly used simple guides.

Rectangular light guides are inefficient since the width of the scintillator is often much greater than the diameter of the PMT. Obstruction between adjacent detectors and PMTs should be minimized, so the guide is usually as wide as the PMT and not the scintillator which would lead to a loss of light at the connection between the scintillator and guide.

Standard fishtail guides consist of gradual tapering in all directions from a rectangular shape to a circular one. Since an input flux of photons cannot be concentrated into a smaller cross-sectional area (Garwin 1952), light collection is low.

A complex adiabatic guide consists of gradual curves and bends. One example is the 90° twisted guide, as in the S1 and S2 layers, which consists of a flat panel cut into strips twisted at 90° so they all line up on the circular face of the PMT. This design usually requires more space as the twisting must be done very gradually in order to avoid sharp curves.

A new design: S-shape

Instead of twisting strips, the new design consists of strips that are bent upward or down and then cut into S-shapes that are curved inward toward the PMT. The small curvature of the S-shape ensures a greater collection. Two options are proposed for the S-shape design: 2-strip and 3-strip. The 3-strip design has an extra rectangular piece located between two of the S-shaped pieces.

MATERIALS AND METHODS

Guide7

Guide7, a Monte Carlo program written in FORTRAN developed by CERN (European Organization for Nuclear Research) to evaluate the properties of scintillation and Cherenkov detectors, was used throughout.

In Guide7, a particle detector's light producing mechanism as well as the geometry and transmission properties of the optical guiding system may be defined. For scintillating light production, photons are emitted isotropically from either a point or line source. The direction of emission is randomly chosen and the path of the photon is extrapolated until it encounters a boundary. At this point it either escapes or reflects, depending on the reflective properties at the surface. If the angle of incidence is greater than or equal to the critical angle with respect to normal, total reflection is assumed, otherwise it escapes. The process continues until the photon reaches the PMT window, escapes, or exceeds a predefined time limit.

Statistical fluctuations

The total time delay of each photon that Guide7 tracks to reach the PMT was entered into an analysis/histogramming program called PAW (PhysicsAnalysis Workstation) from CERN (http://wwwasd.web.cern.ch/wwwasd/paw/); the photons were then sorted into 5 pico-second (ps) bins, giving a distribution of photon propagation time inside the scintillator and guide (Fig

1 - top). In order to investigate the time resolution, statistical fluctuations due to scintillator time response, quantum efficiency and PMT jitter were applied. Scintillator rise and decay was modeled with a simple linear rise and exponential decay:

$$N(t) = \begin{cases} N_{\max}\dfrac{t}{\tau_1}, t \le \tau_1 \\ N_{\max} e^{-\frac{t-\tau_1}{\tau_2}}, \tau_1 < t \le \infty \end{cases}$$

Rise time τ_1= 0.9 nano-second (ns) and decay time τ_2 =2.1 ns were used. The PMT transit time jitter was modeled using a Gaussian distribution with mean of 2 ns and σ = 0.5 ns. The quantum efficiency of the PMT was assumed to be 20% (which is typical for the PMTs used in Hall A).

Photomultiplier pulse shape

According to Wright (http://www.electrontubes.com/info/papers.html), the output of a PMT may be represented as a current generator in parallel with a resistor and a capacitor where R and C are the intrinsic resistance and capacitance of the anode as well as any other components attached to the photomultiplier (anode load, cables). The voltage pulse (Figure 1 - bottom) due to an input current is given by:

$$V(t) = \sum_{t'=0}^{t'=t} N(t')Ve^{\frac{t'-t}{t}},$$

where N(t') is the number of electrons arriving at the anode at t' and V is the voltage drop across the anode. A decay constant (τ=RC) of 0.5 ns was used (Glister 2005).

Setup

Two simple light guides (rectangular and standard fishtail shapes) were compared with the two new designs (2-strip and 3-strip S-shapes). Only simple shapes such as planes and half-cylinders could be modeled using Guide7, which does not leave a way to accurately model the complicated geometry of the twisted light guide (an infinite number of half-cylinders would be needed).

For each guide, thirty separate points of photon emission were chosen in the scintillator. For each of these points, 300 runs were performed of Guide7. The threshold for each pulse to activate the discriminator was set at 5% of the maximum value of the first run with the variation among runs giving the time resolution.

The indices of refraction were set at 1.58 for the scintillator (Polystyrene), 1.49 for the light guide (acrylic), and 1.47 for the photocathode window (glass). A maximum of 10 000 emitted photons, 10 000 accepted photons,

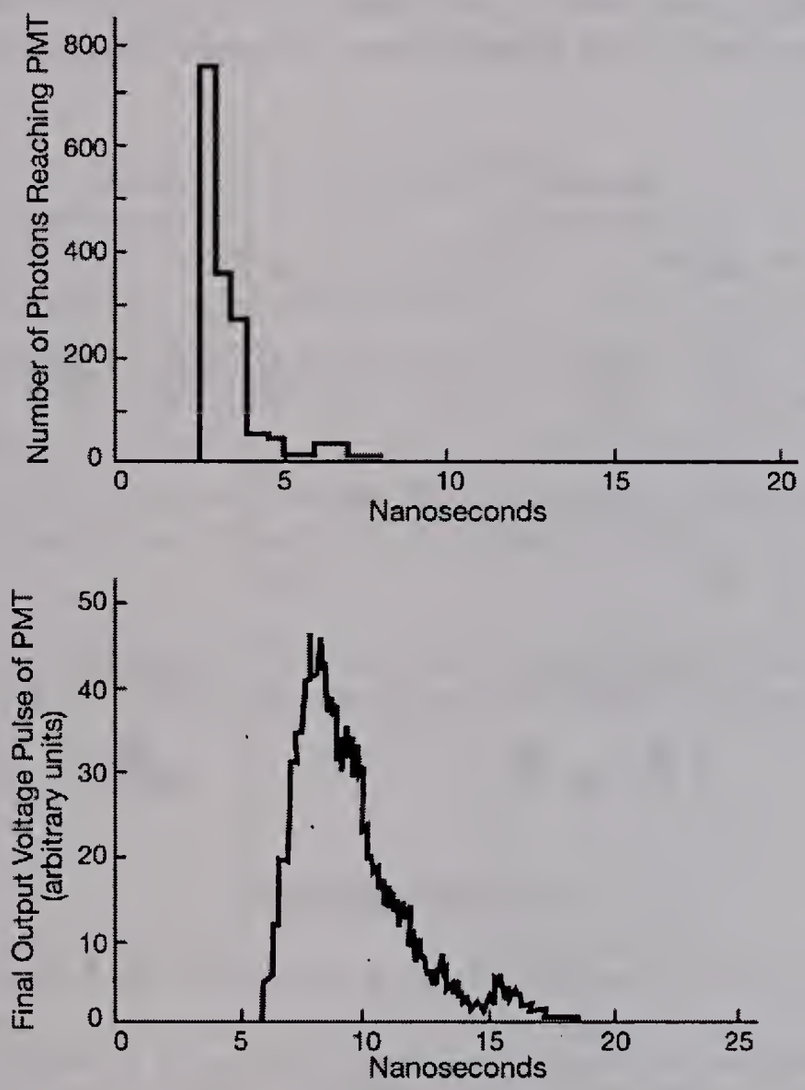

Fig 1 Distribution of photon propagation times in scintillator and light guide and final output pulse of PMT

100 second (s) running time and 30 ns photon time delay were defined. Attenuation length was defined as infinity. All detectors were modeled with a 6 cm long acrylic cylinder attaching the 5 cm diameter PMT to the light guide. Scintillator dimensions of 1 x 10 x 20 cm and guide length of 28.5 cm were used.

Verification of Guide7

Two tests were performed to verify that the guides could be accurately modeled using Guide7. The first test was experimental and compared the angle and position of laser light escape with that of photon escape in Guide7 for varying angles and positions of entrance into a single S-shape strip. Excellent agreement within the limits of experimental uncertainty was found between Monte Carlo simulations and experimental results for the angle of emission.

The other test consisted of plotting photons rejected by Guide7 along with the dimensions of the scintillator and guide to ensure photons were escaping from the predicted locations. After applying a few corrections (found with the aid of this analysis), the photons were recorded as escaping where expected: at the connection point between the scintillator and

guide for the rectangular shape, all along the inwardly tapering edges for the fishtail shape, and in the bend/curves of the 2-strip and 3-strip shaped guides (Fig 2).

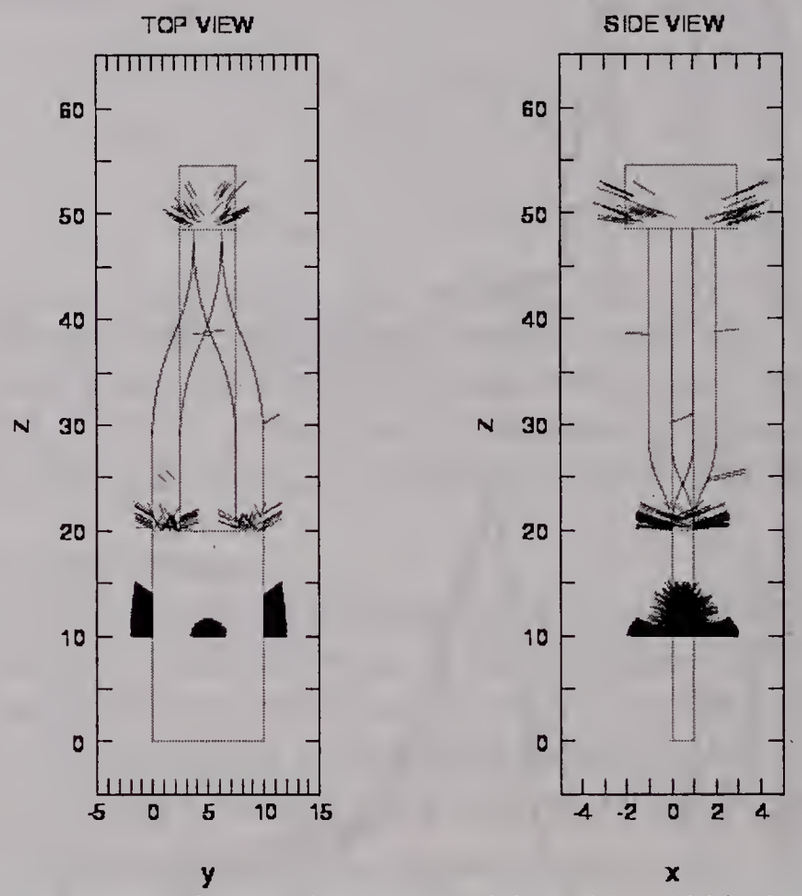

Fig 2 Photons escaping from the 3-strip S-shape light guide. 1000 photons were emitted from centre of scintillator in positive z-direction; all dimensions in cm

RESULTS

Guide7 simulations gave an average collection of 16.37% for fishtail, 18.47% for rectangular, 30.01% for 2-strip and 31.20% for 3-strip shapes. Statistical analysis applied to Guide7 results gave average time resolutions of 0.11 ns for the fishtail, 0.13 ns for rectangular, 0.10 ns for 2-strip and 0.09 ns for 3-strip shapes.

Assuming a minimum ionizing particle depositing 2 MeV/cm and a mean energy of 100 eV/photon, 20 000 primary photons will be created in the scintillator. With a 20% quantum efficiency in the PMT, roughly 1200 photoelectrons will be generated by the PMT for the S-shape guides (compared to roughly 600 in standard fishtail and rectangular shapes). The S-shape guide therefore produces a much stronger signal that can be more easily discerned from background.

It was found that the 6 cm long cylinder at the end of all the guides decreased collection. By removing the cylinder, but keeping the same overall length, the 2-strip and 3-strip S-shape collection improved by roughly 7%.

Gorenstein and Luckey (1963) state that a twisted guide has twice the collection value of a standard fishtail shaped guide one of the same dimensions (0.6 x 41 x 46 cm scintillator, 46 cm long guide and 5 cm diameter PMT), although they state a 12.5% collection for the fishtail shaped guide

which could not be reproduced using Guide7 (we found only 3.5% collection i.e. a more reasonable value for such a large inward taper).

CONCLUSIONS

Based on Guide7's Monte Carlo simulation results, we would recommend that an adiabatic light guide design is a better choice than a simple one. Furthermore, a 3-strip S-shape design offers slightly higher collection efficiency and time resolution than does a 2-strip S-shaped guide for an initial thickness and width of 1 cm and 10 cm respectively and a 28.5 cm total length. A cylindrical connection between the guide and the PMT is not recommended because of the drop in collection efficiency.

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2005 NSIS Scientific Writing Award

RATIONAL DRUG DESIGN: A WINDOW INTO THE AMBITIOUS QUEST OF A NEUROLOGIST AND CHEMIST

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In the difficult world of drug discovery, two main courses of action are open: one is to screen extensive libraries of chemical compounds against hundreds of disease models; another is to acquire a detailed understanding of the molecules involved in a particular disease, and then rationally design compounds that can interact with or block those molecules. The first approach is favoured by large pharmaceutical companies, while the second is favoured by academics. This article illustrates the pursuit of this second approach by a Dalhousie University neurologist and chemist. Through interviews with this scientist and several of his colleagues, the article reveals the science of rational drug design, as well as some of the challenges and compromises involved in bringing discoveries to commercial stages.

Dans le monde difficile de la découverte de médicaments, il existe deux lignes de conduite principales : 1) analyser de vastes bibliothèques de composés chimiques à l'aide de centaines de modèles de maladies; 2) acquérir des connaissances détaillées sur les molécules en jeu lors d'une maladie donnée, puis concevoir de façon rationnelle des composés qui peuvent interagir avec ces molécules ou les bloquer. La première approche est la préférée des grandes entreprises pharmaceutiques, tandis que la seconde a la faveur du milieu universitaire. Cet article illustre un cas d'utilisation de la deuxième approche par un neurologue-chimiste de l'Université Dalhousie. Par le biais d'entrevues avec ce chercheur et plusieurs de ses collègues, cet article révèle la science derrière l'élaboration rationnelle de médicaments, ainsi que certains des défis qui se présentent et des compromis qui doivent être faits lors de la commercialisation des découvertes.

Among the small group of neurologists in Halifax, 'peculiar' can be taken as a compliment. So when lead neurologist Allen Purdy says his colleague Don Weaver is probably one of the most peculiar neurologists he's known, his voice is tinged with pride and awe. "You have to understand," Purdy explained. "He thinks in terms of molecular structures. I'm sure he dreams in terms of molecular structures. He sees things differently."

It's not just any molecular structure that dances around in Don Weaver's head at night. It's a breakthrough drug that prevents epileptic seizures, or reverses the memory loss of Alzheimer's disease. This drug may already exist in the files on his hard drive, or in one of the small vials in his labora-

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tory. The quest to find it and bring it to the people who need it will not be easy, but it will certainly be interesting.

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Today, in front of about a hundred first year science students, Don Weaver picks up a piece of chalk and turns to the blackboard. He is in his late 40s, but seems younger, with intense eyes, a small frame, and mostly brown hair, just slightly balding.

Weaver is a professor of neurology and chemistry at Dalhousie University in Halifax. He sees patients in the neurology division on Mondays and runs a drug design laboratory in the chemistry department the rest of the week. He can also, on occasion, be found in various other locations debating with philosophers, psychologists and even venture capitalists about the nature of the brain and the opportunities to design drugs for it.

Weaver steps back from the black board to evaluate his chalk drawing. It looks like the front of a house with two enormous tennis rackets coming out of the roof.

"I hope you appreciate how painful writing really is for a physician", he says. He explains that the tennis house is supposed to represent a drug called dilantin, and he's given it to many patients with epilepsy. He draws a dotted line around the right side of the house and indicates that's the part that prevents seizures. He then draws another dotted line around the bottom of the house. "This is the part that causes your gums to grow down over your teeth," he says. "I get hate mail from dentists."

Weaver explains that it would be a fairly simple chemical procedure to remove the part of the drug that causes gum growth, while leaving that part that prevents seizures. Years ago, he brought this idea to a big pharmaceutical company. "Their attitude was 'Don't let the door hit you too hard on the way out, but please leave'," he says. The executives explained that it would cost so much money to put that new drug through clinical trials that they could never make their money back with sales. They might be able to make money with a blockbuster, but not from an old drug with different side effects.

Weaver has learned a lot about the pharmaceutical industry since then, and he's not giving up. In fact, he is currently spending $4.2 million in government grants to build the Cheminformatics Drug Discovery Laboratory in Halifax. He's also busy looking for investors for a private biotechnology company.

Today at Dalhousie he approaches the risky reality of drug design with a grim sense of humour. "Most drugs die on the way to the target," Weaver tells the students. "Or they make you die. Either way it's a negative patient outcome."

***

Growing up in North Bay, Ontario, Don Weaver always said that if he couldn't be a hockey goalie, he wanted to do practical science. He turned out to be a terrible goalie so he went to medical school and became a doctor at the young age of 23. In 1980, Weaver started his neurology training at Queen's University in Kingston. He liked to joke that all the other doctors wished they were neurologists; but the truth was, he began to feel that all neurologists did was prescribe decades-old mediocre drugs with absolutely no idea how or why they worked. The epilepsy drugs in particular, had terrible side effects and often didn't work.

When Weaver looked into it, it turned out that every single epilepsy drug had been discovered completely by accident. One drug, phenobarbital, had been known for hundreds of years as a sedative until 1912 when a German doctor, fed up with his patients disturbing him at night, gave them this sedative and found that it stopped their seizures. Another drug, valproic acid, was discovered in the 1960s when a young French chemist dissolved his experimental epilepsy drug in a common laboratory solvent that turned out to be more potent than the compound he'd spent months synthesizing.

Although Weaver had always wanted to do practical science, in 1981 he began to suspect that the most practical thing he could do would be to quit his neurology training and try to make new drugs. He applied to chemistry departments across the country and most of them thought he was crazy, especially since he didn't have an undergraduate degree (he'd gone straight into Medicine after just two years of university). The only school that would accept him into a doctoral program was Queen's. As a result, Weaver has a PhD in chemistry without an undergraduate degree.

Weaver's first drug design strategy was to make small chemical changes to old epilepsy drugs, hoping that some of the new compounds would be better than the old ones. This was the most popular drug design strategy in the early 1980s. But as robotics technology became more sophisticated, the big pharmaceutical companies spent millions of dollars creating random libraries of chemical compounds. Then as today, their main strategy was to screen robotically these compounds against hundreds of disease models. "You've got six million molecules, so one of them has got to work," is how Weaver describes this approach. It can work, but only for disorders that can be modeled in a test tube. Epilepsy is not one of these.

In the mid 1980s, as biologists learned more about the molecular nature of disease, chemists, including Don Weaver, started dreaming of rational drug design. The goal was to figure out the molecular structure of proteins involved in diseases and then use computer models, theoretical chemistry and human intuition to design novel molecules that could interact with those proteins. A computer-designed drug could be tested and optimized using software, but eventually it would have to be constructed from chemicals in the laboratory and tested in the real world. Weaver describes this approach as elegant, attractive and cheap, but horrendously time-inefficient. He says pharmaceutical companies have largely abandoned it to academics while they screen robotically their random libraries.

Besides its elegance, rational drug design holds another lure for academics: it both requires and leads to an ever more intimate understanding of disease. In this way, designing drugs for epilepsy could be the exercise that leads to an understanding of what is probably the most mystifying structure in the universe: the human brain.

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Allen Purdy, a trim man with grey hair and glasses, peers at me across the large stack of papers that covers his desk in the neurology division of the Halifax Infirmary. In 1985, Purdy was a staff neurologist when Don Weaver arrived at Dalhousie to complete his neurology training after finishing his PhD in chemistry.

"When he was a resident," Purdy tells me, "he would think of molecular structures and how he could use quantum physics and other mathematical models to design drugs that would dock and produce effects... It's totally different from most discovery models for epileptic drugs."

Purdy remembers Weaver as 'peculiar', but also as 'bright' and 'funny'. "Every comment made about how good he is," says Purdy, "which is true, he is, is always balanced by either a laugh or a smile or a statement that makes you realize he's up to no good."

After finishing his neurology training at Dalhousie in 1989, Weaver returned to Queen's for 12 years. While he was a professor there (in the chemistry and neurology departments), he also became the president of Epilepsy Canada, won a Financial Post 'Top 40 Under 40 Award' and helped found several drug design companies. One of these companies, Neurochem Inc. of Montreal, now has a drug for Alzheimer's in the last phase of clinical trials.

With Purdy's encouragement, Weaver came back to Halifax in 2001 and has been practicing his unique style of molecular neurology here ever since. This style has its advantages: once, Weaver accused a patient of not taking his seizure pills until he brought the pills to his chemistry laboratory and found they were ruined by the moisture in the bathroom cabinet. Another time, acting on a patient's hunch, he found that a chemical in black liquorice could act as a trigger for seizures. For Weaver, every neurological observation has a chemical explanation, and the insights gained from these connections supply the intuition needed for drug design.

Today in his crowded office, Purdy leans back in his chair and sips the Tim Horton's coffee his secretary brought in. He says Weaver has a desire to deconstruct the brain, but it's balanced by an awe of its complexity. "His balance is basically that he understands he's up against something more difficult and profound that just a bond between two molecules." Purdy says he's up against the greatest philosophical question of all time, which is trying to understand the brain. "Don has the kind of mind that likes to follow that road because there will be no end to it. The more he learns the more there will be to learn."

***

Much of the legwork in this quest falls on Chris Barden, a young scientist designing drugs in Don Weaver's chemistry laboratory. There are five computers in Chris Barden's office but he tells me it's more like eight because one of them is so big it should count for at least three. He calls this big computer "the workhorse," as he flips off the front panel, revealing a dozen thin purple blocks he calls hard drives. In a lecture to the chemistry department, Barden later says his computer has two terabytes of memory, and it worked for several months straight on one of his projects.

Only two of Barden's computer screens are on right now. One displays what looks a little like a sprinkle doughnut rotating around in black space. Barden explains that thousands of these doughnuts are embedded in the membrane of every neuron in the brain. The hole in the middle of the doughnut is where a sort of electricity can flow into or out of the neuron.

The best scientific models of the brain say that thoughts and memories are somehow made up of the tiny electrical signals that pass from one neuron to another. The human brain has billions of neurons, and each neuron has many long fragile fingers that reach out to form trillions of connections. The sprinkle doughnut rotating on Chris Barden's computer screen is a model of one the electrical gates that controls the signals between neurons. Each sprinkle represents an atom and there are thousands of atoms, colour-coded like a rainbow on the black expanse of screen. The doughnut rotates around at different angles when Barden drags it with his mouse.

Epilepsy is a disorder characterized by an electrical short circuit in the brain. Instead of firing an electrical signal, and then waiting for a response, a rogue neuron will continue to fire over and over again; this chaos will spread to nearby neurons and eventually throughout the brain until the patient loses consciousness and possibly begins violent convulsions. In about a third of the cases, the seizures can be traced back to an earlier brain injury, but in most cases, no one knows what causes these short circuits. If the short circuit occurs in a part of the brain involved in vision, the patient may have hallucinations before a seizure. If it occurs in another part, the patient may hear voices, or recall a specific smell.

These doughnut shaped electrical gates may be the key to preventing a rogue neural firing from spreading throughout the brain. And with a click of his mouse, Barden can find the exact 3D location of any atom in the electrical gate. He can also figure out how strongly each atom is attracted to the one next to it. He even has a good idea which part of the molecule acts as a switch to open or close the gate. This, in particular, is a big help if your goal is to design a small molecule to prevent the spread of the electrical short circuit.

"Dr. Weaver provided a unique opportunity," says Barden, while rotating the doughnut around somewhat arbitrarily. "In this small circle of computational chemistry, there are probably only 30 jobs open worldwide. And really, what Don has here may be unique in the entire set-up of education

and further training in drug design." He's referring to the way his boss manages to combine the best from both academia and industry. They get public funding for research, but they also have every opportunity to commercialize their discoveries through industry. They have an open learning environment, but they work more toward patents than publications and as a result often can't discuss details of their research. They attend lectures by both chemists and lawyers.

"He has a curious sense of things," says Barden of Weaver. "He'll come into my office in the morning and say, 'Why is it that animals that are fed entirely on heavy water don't survive?' He had a rather provocative idea that water could act as a neurotransmitter. He'll be the first to say that his ideas may border on fantasy, but they lead to interesting discussions."

They also seem to lead, wherever Weaver goes, to new biotechnology companies. The latest one is called DeNovaMed, and its new headquarters are currently under construction on University Avenue in Halifax.

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On a sunny melting Friday afternoon in February, Chris McMaster squints out his window in Dalhousie's Atlantic Research Centre. He's trying to see if the construction crews across the street are making any progress on the Cheminformatics Drug Discovery Laboratory, the research facility that will also be the new headquarters of DeNovaMed. Scientists across the province and country will be able to use the laboratory's sophisticated computers and equipment to design drugs. Along with Don Weaver and David Byers, Chris McMaster is one of the founders of DeNovaMed.

We put our coats on and jaywalk across University Avenue, trying to avoid the slush. The new building fills prime space between the IWK Health Centre and a large five-story parking garage that was built recently beside the road. We walk into the Health Centre and up a couple of flights of stairs. Someone has wedged open the orange door that leads into the new laboratory, so McMaster eagerly offers me a tour.

The concrete floor is dusty and yellow insulation is still exposed, but there is already some demo office furniture in the corner by the door. Blinds are now drawn over the windows that cover two sides of the large room; one row of windows looks into the hospital lobby, while the other overlooks a roof, pierced by a blue glass pyramid-shaped sunlight. McMaster explains that eight drug design computers will be set up in front of these windows. He says they might convert one window into a door so they can have picnics on the roof.

While this is Don Weaver's fourth biotechnology company, it is a first for McMaster and Byers, both biochemists at Dalhousie University. McMaster explains that he and Byers came up with an idea for a new antibacterial drug several years ago, but they hadn't been able to do anything with that idea until Don Weaver arrived at Dalhousie in 2001.

"Here we had a perfect target, we thought, for an antibacterial," McMaster says of the initial idea, "and we could assay everything we needed to assay, but we didn't have a drug. Don was perfect for looking at protein structures, designing and synthesizing drugs in his laboratory. We set up a little marriage, got together and we showed him all the structures and all the data we had. People in Don's laboratory made twenty different compounds all based on an apparent structure, and we just hoped to death that they actually inhibited our enzyme and killed bacteria. And they did."

McMaster walks over to the row of windows that face the hospital lobby. He peeks behind the blind, and a woman in an office on the other side waves at us. He explains that although they are promoting DeNovaMed as an antibiotic company, Weaver's personal quest for neurologic drugs is also part of the plan.

"The venture capitalists don't want to fund the Alzheimer's and epilepsy projects," McMaster says, "because they're still too far removed from medicines that could actually be used to treat people, whereas the antibiotic projects are closer. We're actually at the point where it's just making drugs and testing them, with some drugs that already look promising." He says it's also helpful that antibiotics are usually taken only for a couple of weeks, so they don't require long-term clinical trials. With a neurologic drug that a patient might take for ten years, the cost of a clinical trial could easily be many times greater than for an antibiotic.

The DeNovaMed founders are hoping that Chris Barden will become the president of the new company, but nothing is official until they get some venture capital funding. Investors are wary because drug design is an extremely risky business.

"It's a big gamble," says McMaster, but he hopes the Cheminformatics Drug Discovery Laboratory will give them a head start.

***

Cold February drizzle drips outside Don Weaver's window in the Dalhousie University Chemistry department. Two grey squeeze-toy brains sit on top of the computer monitor in his office. His mouse pad is a blue and pink cross section of brain. On the walls, anatomy posters mingle with Renoir prints and pictures of his two teenage boys.

Weaver sits in a small swivel chair and tells me why he's spent most of his career trying to understand epilepsy: "I was totally fascinated by the fact that people with seizure disorders are sitting there, and you're having a conversation with them, then they're unconscious for two minutes, and then they blink their eyes and they're back. As a medical student and as a neurology resident, I went, 'They have a lot to teach us!' You know, we can learn a lot on how the brain works and all the rest of it from people who have seizure disorders. So I became fascinated by that. And as I mentioned in the chemistry lecture, I sort of like to look at trying to understand the combination of brain and mind and consciousness."

Weaver is referring to a lecture he gave on the Chemistry of Consciousness the previous fall at Dalhousie's Open House for students and the public. He explained that the deepest mystery of all, to him, was how a three-pound sac of grey mush could give us emotions, memories and a sense of self-awareness – a sense of being conscious.

Weaver used the opportunity of this special lecture to tell the stories of some of his most fascinating patients. They were hard to forget. There was the man who saw a giant fireball bowling toward his head before every seizure. When the fireball got too close, he would duck for cover and lose consciousness. The patient was an intelligent man, and he recognized the absurdity of a fireball coming at him in the middle of his living room or the grocery store or wherever he happened to be. But in the end, he could never face it. In the end it was always real. Another patient heard Barney Rubble say 'Hello neighbour... What are you up to today Fred?' before every seizure. During the lecture I wondered why these particular memories were always linked to the onset of a seizure. Could one damaged neuron, the neuron that remembered a specific episode of the Flintstones, be responsible? What does this tell us about our seemingly intangible memories?

"If we really want to figure out how the brain works," Weaver had said, "human illness provides us with experiments of nature."

Unfortunately, new epilepsy drugs can't be tested in human experiments of nature. The only real models for the disorder are rats, and it is very difficult to give a rat epilepsy. The current protocols involve either gruesome brain trauma or poisoning; and it is a fine line between giving a rat epilepsy and killing it. Unlike antibiotics, there is no good model in a test tube. Weaver says there are no pharmaceutical companies designing drugs for epilepsy today. The potential sales are just not worth the cost of development and testing.

I ask Weaver how the he ended up in a company designing antibiotics when the brain has been his passion for so long.

"This is a business move," he says, "because the biotech sector has been burned a lot lately, and they want something that has a faster payoff. And it's easier to develop antibiotics just because the biological testing is faster."

Weaver is realistic about his options. "We want to get molecules that make it to people that cure diseases," he says, "and whether one likes it or not, the only way to do that is within industry. No government develops drugs. No university has the commercial means to develop drugs. The World Health Organization does not develop drugs. I mean the only group out there that develops drugs, is industry. And I mean you can have all these philosophical debates about it and that's fine, but as it currently stands in 2005 the only group that's going to get a drug to people is industry."

Weaver does not seem bitter at the compromises he's had to make. His goal is to develop drugs to treat neurological disorders, and he will do whatever it takes to get there. He says one of the most difficult decisions he had to make was to leave Queen's University for Dalhousie in 2001. He explains that several neurologists had left Kingston, and his responsibilities

in the clinic kept increasing to the point that he was barely in the chemistry laboratory.

Upon hearing that Weaver was leaving, a long time patient from Kingston wrote: "I had just gotten to the point where I felt I had properly trained Dr. Weaver to the quirks of my condition. More important, I had grown accustomed to his sense of humour." He later adds: "Don's leaving is more important to me than just another doctor leaving the area. You see Dr. Weaver saved my life. He was more than a neurologist to me. He was my advocate when I needed it, my cheerleader when I felt I could no longer carry on this battle."

The patient, Tim Eichholz, later tells me "I wish everyone could see him as a neurologist, but his goal is to develop new drugs. If five years from now, he develops a drug that stops all seizures, I wouldn't be surprised."

In lectures to the public and his students, Weaver always explains it the same way, and he does so once again in his office. "The way I always word it," he says, "is a practicing physician can help people one at a time. But you make a drug that has widespread application and boy, you can touch a whole bunch of people."

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Volume 43, Part 2, pp. 245-252

NOVA SCOTIAN INSTITUTE OF SCIENCE
SESSION 2004-2005

PRESIDENT'S REPORT

Once again the Institute has had a very good year, with a varied program of activities. Our mainstay program, the regular monthly lecture series (Appendix), covered a range of topics and was generally well attended, sometimes drawing capacity audiences to our regular venue in the Nova Scotia Museum of Natural History. This was due not only to the efforts of our Publicity Officer (Susan Bjornson) and Secretary (Linda Marks), but also to some much-appreciated advertising by other organizations: the Nova Scotia Museum, in its "Events" newsletter and announcements over CBC radio, the Discovery Centre in its brochure, and the Halifax Field Naturalists. We are grateful for their interest and support.

The Institute was also pleased to co-sponsor two special events in October: a special lecture at Dalhousie University by Nobel Laureate (Physiology/ Medicine 1981) Dr. David Hubel, and a workshop at St. Mary's University to consider ways of maintaining the research station on Sable Island. The latter event was instrumental in resolving the problems of financial support of the station, and it is good to be able to report that the future of this important facility now seems assured.

After having several ad hoc caretakers of the Institute's website, we were pleased to welcome John Cordes to the Council as continuing webmaster. John brings considerable expertise to this job and has updated and revamped the site. Thanks are extended to student member Andrew Hamilton, who maintained the site for over a year until his departure from the province last August.

During the year, we updated the membership list and organized a campaign, spearheaded by Treasurer Steve Ewart and Membership Chair Georgia Pe-Piper, to collect dues in arrears. We also reinstated the annual autumn dues levy (albeit in winter), since soliciting dues via the AGM notice alone was not very successful, as response seemed to be linked to attendance at the AGM dinner and few members knew their dues status. Despite the perennial difficulties with dues collection and recruitment of new members, our finances are in good shape under Steve's care, as detailed in his Treasurer's report.

Thanks to this financial good health, we were able to continue our sponsorship of science education via Science Fairs and the Student Writing Competition. This year the Institute sponsored awards in all eight Regional Science Fairs in the province, donating $100 to each region. Thanks go here to Surjit Verma for again acting as liaison to the fair organizers.

Our third annual student writing competition attracted a number of excellent papers, from nearly all Nova Scotian universities that have a science curriculum. Five awards totaling $1500 were made, to: David Conrad (Dal-

housie University, graduate award), Jackie Glister (St. Mary's University, undergraduate award), Mark Wall (University College of Cape Breton, undergraduate award), Jennifer Paterson (University of King's College, scientific journalism), and Jane Tougas (Dalhousie University, special award for high merit in the graduate category). The competition was again very capably and efficiently coordinated by Jonathan Blay, assisted on the judging committee by Stuart Grossert and myself, and by additional readers S. Bjornson, J. Cordes, E. Curry, P. Keast, A. McCulloch, B. Pohajdak, K. Rouvinen-Watt and D. Tindall. The participation of all these people is greatly appreciated.

The Mentorship Program initiated last year is now in operation, with about 20 mentors registered and several students requesting and being referred to mentors. Thanks for continuing this initiative go to Sean Tibbetts (Chair).

It has been an active year in the editorial office and library, as set forth in the respective reports of Jim Stewart (Editor) and Sharon Longard (Librarian). I wish to take this opportunity to acknowledge with thanks the work of these officers. Mention should also be made of our two enthusiastic student representatives Derek Schnare (St. Mary's) and Alexis Paton (Dalhousie). Students bring a fresh perspective and Derek has noted that he enjoyed his two years with us so much he was willing to continue even while at law school! Alexis will be returning next year. I also wish to thank our observers, Alex Wilson (Nova Scotia Museum) and Dena Simon (Discovery Centre), who have been helpful far beyond the call of duty.

Finally, I would like to convey my sincere appreciation to all members of the Council for their support and active participation in the Institute's programs, toward a successful year. In particular, I want to recognize our Secretary, Linda Marks, our Past-President, Archie McCulloch, and Vice-President, Stuart Grossert. Their unfailing good humour and spirit of cooperation have made my job a pleasure. It has been an honour to serve the Institute in this capacity.

Presented to the AGM
May 2, 2005
Carolyn Bird
President NSIS

APPENDIX:

Regular Lectures

October 4: *The life work of Donald O. Hebb, Canada's most famous psychologist.*
Richard Brown, Dept. of Psychology, Dalhousie University

November 1: *The LIDAR in Laser Atmospheric Studies at Dalhousie University.*
Tom Duck, Department of Physics, Dalhousie University.

December 6: *Fates of po!ycyclic aromatic hydrocarbons in marine organisms.*
Jocelyne Hellou, Marine Chemistry, Fisheries and Oceans Canada

January 3: *How to protect your computer from hackers.*
Peter Steeper, Xerox Canada

February 7: *Antibiotic use on the farm. Implications for human health?*
Kevin Forward, Faculty of Medicine, Dalhousie University

March 7: Filling the void-discovering life beneath the seas.
Ellen Kenchington, Fisheries and Oceans Canada

April 4: *Hurricanes and their impact on the forests of Nova Scotia.*
Peter Neily, NS Department of Natural Resources

May 2: *The role of materials research in your daily lives.*
Mary Ann White, Department of Chemistry, Dalhousie University
Annual Dinner Speaker

Special Events

October 5: *Sable Island: uncertain future?*
Workshop with special presentation by **Zoe Lucas**, biologist and long-time resident of Sable Island
[co-sponsored by St. Mary's University, the Ecology Action Centre, and the Sable Island Green Horse Society]

October 18: *Vision and brain: the results of a half century of research*
Dr. David Hubel, Department of Neurobiology, Harvard University
[co-sponsored by the Dalhousie Institute of Neuroscience]

LIBRARIAN'S REPORT

There are currently one hundred and ninety-one NSIS exchange partners, and this number has not changed from the previous year. The number of institutional members also remains unchanged from last year and continues to be twenty-seven. Invoices were sent out in February 2005 for institutional memberships and to date we have received payment for twenty renewals.

In March 2004 volume 42, Part 2, of the *Proceedings of the Nova Scotian Institute of Science* was published. The Library mailed the issue to exchange partners and institutional members. in addition, we also did the mailing to personal members. Postal charges for distribution of the printed journal cost the Institute $1,713.19 in 2004.

The *Flora of Nova Scotia* by A.E. Roland continues to sell @ $15.00, and thirty-three copies were sold during the period May 2004-March 2005. There are only nineteen remaining copies of the Flora available. Once these are sold the title will be out of print.

Publications continue to be received regularly from our 191 active exchange partners and this material is added on an ongoing basis to the collection. I would like to thank Carol Richardson and the Serials Department staff in the Killam Library who ensure that the NSIS Library operations continue to function smoothly.

Respectfully submitted to the AGM
May 2, 2005
Sharon Longard
NSIS Librarian

EDITOR'S REPORT

1) The Proceedings of the Nova Scotian Institute of Science Volume 42 Part 2 was published in the spring of 2004. This relatively large issue is comprised of 269 pages and included 13 papers on Conserving Biodiversity in Nova Scotia edited by JH Martin Willison and Christopher Miller. In addition, it included two papers from the NSIS student Science Awards program begun in 2003, three obituaries and the NSIS Sessions Proceedings for the 3 years 2000-2003.
2) The preparation of the first part of Volume 43 is well advanced. Currently, galleys for review by authors of most of the papers are being printed; this step should be virtually complete by the end of the month i.e. about the time of the AGM. Two papers are still being prepared, but are expected to be completed shortly. As a result, this issue should be ready for distribution by the summer of 2005. This issue, in addition to several general papers, will carry papers from the 2004 NSIS Student Science Awards program plus the report on NSIS Sessions for 2003-2004.
3) Material for the written Symposium on Marine Science has taken longer to prepare than was anticipated. Much of it now, however, is in hand and it is expected it will appear in Part 2 of Volume 43 before the end of 2005.

Respectfully submitted to the AGM
May 2, 2005
James E. Stewart
Editor NSIS

TREASURER'S REPORT

ASSETS:			
Bank Account	$6,177.88		
Petty Cash	0.00		
		6,177.88	
Investments		50,724.11	
Account Receivable			56,901.99
			56,901.99
LIABILITIES AND NET WORTH:			
Accounts Payable (Science Fair cheques)			-200.00
Total Liabilities and Net Worth			**56,701.99**

INVESTMENTS:	
Cash Balance	3,170.41
CIBC Premium T-Bill (short-term)	9,157.70
CIBC Investment Certificate A @4.40% (due Apr 2008)	8,396.00
Citizens Bank Certificate A @3.60% (due Feb 2006) Can	10,000.00
Western Bank Certificate A @ 3.30% (due April 2006)	10,000.00
National Trust GIC @5.20% (due May 2005)	10,000.00
	50,724.11

Revenue

Membership Dues		
Individuals	$1,040.00	
Institutions	472.10	
AGM (2004)	786.75	
Donations	50.00	
Sales/Page charges		
Proceedings	2,984.93	
Other	500.50	
Interest (chequing acct)	4.13	
	$5,838.41	Total

Expenditures

Advertisement/promotion	$228.88	
AGM (2004)	939.64	
Office supplies	161.95	
Rent (Museum)	175.00	
Proceedings printing	8,814.04	
Donations/Prizes	800.00	
	$11,119.51	Total

Net: ($5,281.10)

Treasurer's Report (continued)

Notes

Finances

The Institute' s finances are in good shape. They have been relatively stable over the last few years. The net worth, $56,701.99, compares well with that of the previous year ($61,602.37)[1].

As in past years, we received a grant from the NS Museum of $1000.00. This is not reflected in this year's finances because the cheque was sent to Dalhousie University (address of former Treasurer) and deposited into an account there. I arranged with Dalhousie for a reimbursement cheque. This was deposited into our account in April.

Dr. Archie McCulloch and Dr. David Jamieson informally audited the finances of NSIS this year. Their diligent efforts are much appreciated.

Membership

Membership dues in 2004/2005 amounted to $1040. This was lower than the total ($2000) collected the previous year. This was, in part, the result of several members paying for two years in 2003/2004. Also, $300 in dues were deposited in April and not reflected in 2004/2005 fiscal year (end March 31st).

Current membership is 121 members:

~ 88 Regular members (dues paid for 04-05)
~ 24 Regular members (owing for 04-05)
~ 5 Student members
~ 4 Life members

Of these 13 are new regular members

24 members who were in arrears for more than two years have been removed from the membership list. Additionally, 5 members requested to be removed from the membership list.

Respectfully submitted to the AGM
May 2, 2005
H Stephen Ewart
Treasurer

[1] Reported as $61,202.37 and corrected to $61,602.37 following the audit.

AUDITORS' REPORT

We have examined the financial records and books of the Nova Scotian Institute of Science and have determined that the financial statement prepared by the Institute Treasurer fairly represents the financial status of the assets for the fiscal year ending 31 March 2005.

We offer three recommendations:

1) An annual invoicing of members who have not prepaid their dues should be conducted in September or October.

2) The Institute should consider changing their fiscal year to end at the last day of February. This would allow sufficient time for complete financial records to be readily available for audit.

3) The annual financial statement should provide a breakdown of printing and mailing costs associated with the publication and distribution of the Proceedings.

Respectfully submitted to the AGM
2 May, 2005
W. David Jamieson
Archie McCulloch

Instructions to Authors

The *Proceedings of the Nova Scotian Institute of Science* publishes papers in English or French. Manuscripts must be typewritten double-spaced with 4 cm margins. Disk copies in Word or WordPerfect are preferred, but must also be accompanied by three paper copies of the manuscript. An abstract of no more than 200 words, free of formulae, must be included at the beginning of the paper, followed by key words or phrases. This should be followed by an introduction, methods, results or observations, discussion and references. In some cases a combination of these sections may be more effective. Underline only material to be set in italics, and use capital letters only when the letters or words should appear in capitals in the printed paper. Layout and style should follow that used in recent volumes. Each page of the manuscript should be numbered, the first page carrying only the title, authors' names and affiliations and any necessary footnotes. Spelling should follow that of Webster's Third New International Dictionary. Abbreviations, nomenclature, and symbols for units of measurements should follow international recommendations. SI units should be used whenever possible. Use day-month-year sequence for dates. Do not use periods after abbreviations. Photographs should be mounted on Bristol board ready for reproduction. Prints must be of high quality on glossy paper with no space between those mounted in groups. Color illustrations will be accepted at the discretion of the Editor. The cost of color reproduction is borne fully by the authors who must submit a statement accepting this responsibility. References are to be collected at the end of the paper and referred to in the text by inclusion of the author's name and year of publication. The list of references should be consistent with the following examples:

Periodicals	Nielsen KJ, Franz DR (1995) The influence of adult conspecific and shore level on recruitment of the ribbed mussel *Geukensia demissa* (Dillwyn). J Exp Mar Biol Ecol 188:89-98
Books	Cushing D, Walsh J (1976) The ecology of the seas. WB Saunders Company, Toronto
Papers from books or symposium proceedings	Lee GF (1975) Role of hydrous metal oxides in the transport of heavy metals in the environment. In: Krenkel PA (ed) Heavy metals in the aquatic environment. Pergamon, Oxford, p 137-147
Pers. comm.	Smith AJ (2001) (Nova Scotia Department of Agriculture, Halifax) Personal communication

Tables should be numbered consecutively in bold-faced Arabic numerals and must have brief titles that are self-explanatory; each table must be typed on a separate page.

Illustrations are to be numbered consecutively in Arabic numerals. Captions should be self-explanatory and typed on a separate page. Two paper copies of each are required even when they are embedded in an electronic file. All lines in drawings must be of suitable thickness to reproduce well when published in the *Proceedings*. Similarly, letters and symbols in drawings should be at least 2 mm high when reduced to the size used in the *Proceedings*.

Page Charges. Currently a charge of $25 per page is levied to help defray the cost of publication. This amount is charged to the institution or a contract supporting the research reported in the published paper. In no case will acceptance of the paper be dependent upon payment of the page charges.

Authors are responsible for editing the galley proofs. Orders for reprints, in addition to the 15 supplied gratis to the corresponding author, must be received when the galley proof is returned.

Papers should be sent to the Editor:

JE Stewart, Department of Fisheries & Oceans
Bedford Institute of Oceanography, PO Box 1006
Dartmouth, NS, Canada B2Y 4A2
E-mail: stewartje@mar.dfo-mpo.gc.ca

Recommandations aux auteurs

Le Proceedings of the Nova Scotian Institute of Science publie des articles en anglais ou en français. es documents soumis doivent être dactylographiés à double interligne avec des marges de 4 cm. On éfère recevoir le texte sur disquette en format de traitement de mot Word ou WordPerfect ainsi que trois pies imprimées. Au début de l'article, on exige un résumé n'excédant pas 200 mots, sans formules et ivi de mots ou d'expressions clés. Cette partie devrait être suivie par l'introduction, les méthodes, les sultats ou observations, la discussion et les références bibliographiques. En certain cas, il sera peut-être us efficace de combiner quelques parties. Soulignez seulement ce qui devrait paraître en caractères liques et écrivez avec une majuscule seulement ce qui devrait être imprimé en majuscule. Les détails présentation et de style devraient suivre un numéro récent de la publication. Chaque page de l'article vrait être numérotée et la première page ne portera que le titre, les noms d'auteurs, leurs adresses spectives et toute note infrapaginale qui s'imposera. L'orthographe doit suivre Le Grand Robert et les ccents doivent être insérés sur les majuscules. Les abréviations, la nomenclature et les symboles seront nforme aux recommandations internationales. Où possible, utilisez le Système international d'unités. 'ajoutez pas de point aux abréviations. Les photographies devraient être montées sur une carte Bristol êtes à reproduire. Les épreuves doivent être de qualité supérieure et aucune espace devrait séparée ne collage d'un groupe de photographies. Les illustrations en couleurs seront acceptées comme l'éditeur cientifique jugera à propos. Les coûts de reproduction en couleurs seront aux frais des auteurs qui dev- nt émettre une déclaration acceptant cette responsabilité. Les références bibliographiques devraient araître à la fin de l'article et devraient être citées dans le texte à l'aide des noms d'auteurs et de l'année publication. Veuillez, s'il vous plait, abréger les titres des journaux selon le 'BIOSIS Serial Source', ernière édition, et respecter strictement le format PNSIS (voir les exemples suivants).

ériodiques	Nielsen KJ, Franz DR (1995) The influence of adult conspecific an shore level on recruitment of the ribbed mussel Geukensia demissa (Dillwyn). J Exp Mar Biol Ecol 188: 89-98
ivres	Cushing D, Walsh J (1976) The ecology of the seas. WB Saunders Company, Toronto
rticles de vres ou de ompte rendu	Lee GF (1975) Role of hydrous metal oxides in the transport of heavy metals in the environment. In: Krenkel PA (ed) Heavy metals in the aquatic environment. Pergamon, Oxford, p 137-147
ommunication ersonnelle	Smith AJ (2001) (Nova Scotia Department of Agriculture, Halifax) Personal communication

es tableaux doivent être numérotés de façon continue en chiffres arabes et en caractères gras. Chacun doit omporter un bref titre qui s'explique de soi même et doit être dactylographié sur une page distincte.

es illustrations sont numérotées en chiffres arabes selon leur ordre séquentiel. Les légendes devraient 'expliquer de soi même et devraient être dactylographiées sur une page distincte. On exige deux cop- s imprimées de chaque illustration même quand elle fait partie d'un fichier électronique. L'épaisseur es lignes sur une illustration doit être suffisante pour que la reproduction soit nette à la grandeur de la ublication. De façon semblable, le lettrage et les symboles des illustrations devraient être au moins 2 m de haut quand elles paraîtront dans le Proceedings.

rais de publication. Des frais de 25,00 $ par page sont présentement imposés afin de subvenir une ortion des frais de publication. Ce montant est imputé à l'institution ou au contrat qui appuie la recherche résentée dans l'article. L'acceptation de l'article pour publication ne reposera jamais sur le paiement les frais de publication.

es auteurs sont responsables pour la revue des épreuves en placard. On doit recevoir les commandes our des tirés à part, en plus des 15 qui sont fournies gratuitement à l'auteur correspondant(e), quand ous retournerez les épreuves à placard.

Soumettez vos articles à l'editeur scientifique:

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